11

218

218

: HAND WRITTEN NOTES:-

OF

1

LECTRONICS & COMMUNICATION ENGINEERING

-: SUBJECT:-

EASURMENT & INSTRUMENTATION

11

2

PAGE :
DATE : / /

3

12B

Instrument :

4

- (Indirect)
  - Absolute instrument
- (Direct)
  - Secondary instrumt
    - (Mode)
      - Analog instrument
        - How they indicate the end of Measurement.
          - Deflecting
            - Type of o/p
              - Indicating Instrument
              - Integrating Instrument
              - Recording instrument
          - Null Deflection
      - Digital instrument

MEASUREMENT

Measurement – Measurement is a process of comparison between a Std and an unknown resulting in knowing the magnitude of the unknown in terms of standard.

Instrument – Instrument is a device that facilitated this comparison.

The 2 most essential characteristics of an electrical instrument are

- (i) The operational power consumption should be minimal.

- (ii) The instrument should not change the ambient condition for the ckt in which it has been introduced.

Absolute instrument are those which gives the value of parameter under measurem. in terms of the physical constant of instrument. These instrument based on their operation on the indirect methodology of measurement & since they contain less no. of moving mechanical parts they are highly accurate. These instruments are used in Std. inst. Calibrating laboraties and typical examp of these instrument are tangent galvanom & rayleighs Current balance.

2. The secondary instrument give their o/p directly in terms of the parameter under measurement.

3. These instrument based their operation on the direct methodalogy of measurement & since they contain large no. of moving mechanical parts they are relatively less ~~inaccurate~~ accurate. These instruments are generally used for day to day measurement in the industry and typical example of secondary instrument are Ammeter, Voltmeter, Watt meter etc.

4. An analog instrument is the one whose o/p varies continuously w.r.t time all the while maintaining a constant relationship with the i/p.

5. A digital instrument is the one whose o/p varies discretely w.r.t time all the while maintaining a constant relationship with i/p.

~~6. A digital instrument is the one whose o/p varies discretly w.r.t time~~

6. Deflecting instruments are those which indicate their end of

measurement with the deflection of a pointer away from the zero position. 7

Note: Due to finite amount of power consumed in order to indicate the value under measurement these instruments are relatively less accurate.

7. Null deflection instrument are those which indicate their end of measurement with zero or NULL deflection.

8. Due to Negligible power being consumed at the end of the measurement these instrument are highly accurate.
Ex: AC & DC bridges.

9. An indicating instrument is the one which gives the instanteneous value of the parameter under measurement.
Ex: Ammeter, Voltmeter, Wattmeter, etc

10. An integrating instrument is one which gives the sum or total of the electrical parameter consumed over the period of time
Ex: Energy meter.

11. An recording instrument is the one which gives the historical ~~instrument~~ information about the measurement in terms of a Continuous

DATE : / /

record of the measurement over a specified period of time.
Ex : Recording Voltmeter.

(8)

Essential of an indicating instruments:

The three essential forces that are required by an indicating instrument in order to efficiently indicate the value of parameter under measurement are :

(i) The Deflecting torque.
(ii) Controlling torque (Restorting torque).
(iii) The Damping torque

Deflecting Torque :

The Utility of the deflecting torque is to deflect the pointer away from the zero position. It is produced by the parameter under measurement itself due to one of those effect of electrical current which converts electrical energy into mechanical energy. The magnitude of deflecting torque produced in an indicating instrument

is proportional to the parameter under measurement.

Controlling Torque:

The controlling torque has a two fold utitity.

- (i) It bring the pointer to rest at the steady state position where the angular displacement pointer is proportional to the magnitude of the paramater under measurement
- (ii) It bring the pointer to zero position when the parameter under measuremen is removed from the terminal of instrument.

→ The Controlling torque is ~~Controlling~~ produced by a control mechanism and the most commonly used control mechanism are "spring control mechanism" and "Gravity Control mechanism"

(A) Spring Control

$$\boxed{T_c = K\theta}$$

Where,

K = Spring Constant
= Control Constant
= Restore Constant
= Torsion Constant

$$\boxed{T_c \propto \theta}$$

$$\boxed{T_c = \frac{Ebt^3}{12l} \cdot \theta \ Nm}$$

E = Young Modulus N/m^2
b = Width of spring 'm'
t = thickness 'm'
l = length 'm'
θ = angular deflection 'ra

Assume

$T_d \propto I$

and we know,

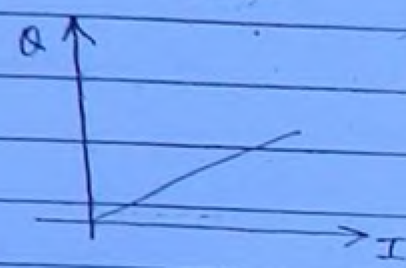
$T_c \propto \theta$

at steady state,

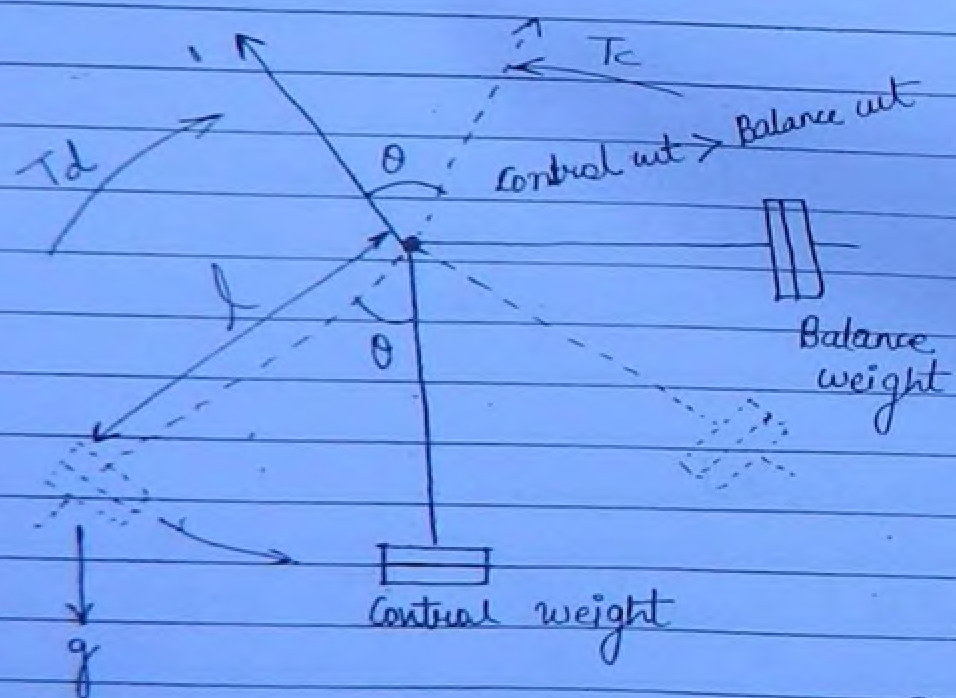
$T_c = T_d$

$\boxed{\therefore \theta \propto I}$

Uniform Scale



(B) Gravity control mechanism



$\boxed{T_c = w \cdot l \cdot \sin\theta}$ N-m

l = distance of control weight from spindle

$w = m \cdot g$ = weight of the controlling weight.

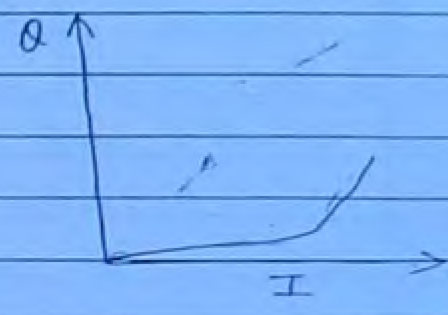
$T_c = K \sin\theta$

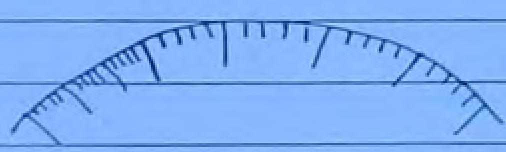
$\boxed{T_c \propto \sin\theta}$

Assume $\boxed{T_d \propto I}$ and as we know $\boxed{T_c \propto \sin\theta}$

At ~~steady~~ Steady position

$\boxed{I \propto \sin\theta}$





Note: The gravity control mechanism is used in instance where the instruments are being used for continuous monitoring and are generally mounted on a panel in the vertical position.

: The spring control mechanism is used in instances where, the instrument is being used as a table top laboratory typ instrument intended for periodic usage.

→ The essential qualities of a spring that is used as a control mechanism are,

- (i) It should undergo minimal mechanical stress. ~~to~~
- (ii) It should be non-magnetic by nature.
- (iii) Control springs are generally made up of 'Phosphor-Bronze'.

DATE : /

→ The utility of the damping torque is to damp the oscillation of the pointer at the steady state position.

This torque is produced by the damping mechanism and the various damping mechanisms used are

(a) air friction damping mechanism

(used when the operating field that produces the deflecting torque is weak).

(b) Eddy Current damping Mechanism.

(Used when the operating field that produces the deflecting torque is strong).

(c) Fluid friction damping mechanism

~~(used when the operating field that produces the deflecting~~

(used in electrostatic instruments for the measurement of high voltages).

Q1. The dimensions of a control spring are given as $l = 370$ mm, $W = 0.51$ mm, $t = 0.073$ mm and $Y = 112.8$ Giga $\frac{N}{m^2}$. Calculate the torque due to the spring when it is turned through an

indicates the "time response" of an Instrument.

Note: The damping constant of an indicating instrument should be around 0.9 i.e (It should be slightly under damped in order to give reading efficiently)

angle of 90°.

θ = in radians
Y = in N/m2
T = N-m
l, w, t = in meters

Soln:
$$T = \frac{112.8 \times 10^{9} \times 0.51 \times 10^{-3} \times (0.073)^3 \times 10^{-9}}{12 \times 370 \times 10^{-3}} \cdot \frac{\pi}{2}$$

$$\therefore T = 7.91 \times 10^{-6} \text{ N-m}$$

13

Q2) The controlling torque in an indicating instrument is given by 16×10^{-6} N-m. If the length and the width of the spring is doubled and its thickness is half calculate the Torque acting on the spring for the same deflection.

Soln

As given, $T_c = \frac{Ebt^3}{12l}\theta = 16 \times 10^{-6}$ N-m

$$= \frac{E(2b)(t/2)^3 \cdot \theta}{12 \times (2l)}$$

$$= \frac{1}{8} \frac{Ebt^3}{12l} \cdot \theta$$

$$= \frac{1}{8} \times 16 \times 10^{-6}$$

Q3) Assertion (A): The needle of an indicating instrument attains a position where the deflecting and the controlling torque acting on the moving system are equal and opposite

Reason (R): The oscillation of the needle are suppressed by the damping mechanism.

a) Both A and R are true and R is correct exp
b) Both A and R are true but R is not correct
c) A is true, R is false.
d) A is false, R is true.

P.Q.

Source – applied	Source – Applied
Pointer – just about to move	Pointer – Moving
$T_d = T_{d(max)}$	$T_d = T_{d(max)} - T_c'$
$T_c = 0$	$T_c = T_c'$

PAGE :
DATE : / /

Q4) As the pointer of the indicating instrument deflects away from zero position
P.S.U
a) Its deflecting torque increases, T_c decreases
b) T_d decreases, T_c increases.
c) Both increases
d) Both T_d and T_c decrease.

14

Q5) As the pointer of the indicating instrument moves away from the zero position, the magnitude of the damping torque acting on the pointer
P.S.U
a) will increase with ↑ deflection
b) will ↓ with ↑ of deflection.
c) will remain constant throughout the deflection
d) will be zero.

Q6) A 0–5 A PMMC Ammeter is supplied with a current of 2.75 A. If the instrument is designed without a control mechanism and its moving system is free to rotate the pointer of the instrument will
a) Indicate value > 2.75 A but < 5 A
b) Indicate value of 5 A.
c) oscillate between 0 and 5 A.
d) Rotate Continuously for 360°

Note: The pointer in this case will rotate continuously for 360° as long as the parameter under measurement is applied to the terminal of the instrument. Once the current is removed from the terminal the pointer is stoped at the arbitrary position where the net deflecting torque acting on the pointer can no longer overcome forces due to friction.

INDICATING INSTRUMENTS

- Magnetic effect
  - Moving Coil
    - ** (DC) → PMMC ($\theta \propto I$)
    - → Electrodynamometer Instrument ($\theta \propto I_1 I_2$)
      - → Power
  - Moving Iron ($\theta \propto I^2$) (AC/DC)
    - → Attraction Type
    - → Repulsion Type
- Electrostatic effect ($\theta \propto V^2$)
  - (i) Quadrant Electrometer
  - (ii) Kelvin Multicellular Voltmeter
  - (iii) Absolute / Attached disk electrometer
- Thermoelectric effect ($\theta \propto I^2$)
  - (i) Hotwire Instrument
  - (ii) Thermocouple Instrument
  - (iii) Bolometer.
- Induction effect ($\theta \propto I$)
  - (i) ~~Splitting~~ split ring Inst.
  - (ii) Shaded Pole Instrument

PAGE :
DATE : / /

Note :

— (i) If the angle of deflection of an indicating instrument is proportional to either the square of or the product of the parameter under measurement then the instrument is said to exhibit a "square law response". (16)

— (ii) From the above classification it can be seen that all the instrument except the PMMC instrument exhibit a square law response.

— (iii) The electrostatic type of instrument which are also known as Electrometers are used as Voltmeters only that too for the measurement of R.M.S Value of an a.c Voltage of a high magnitude (in KV range) of any wave shape.

$$\boxed{I_{rms} = \sqrt{I_{DC}^2 + \left(\frac{I_m}{\sqrt{2}}\right)^2}}$$

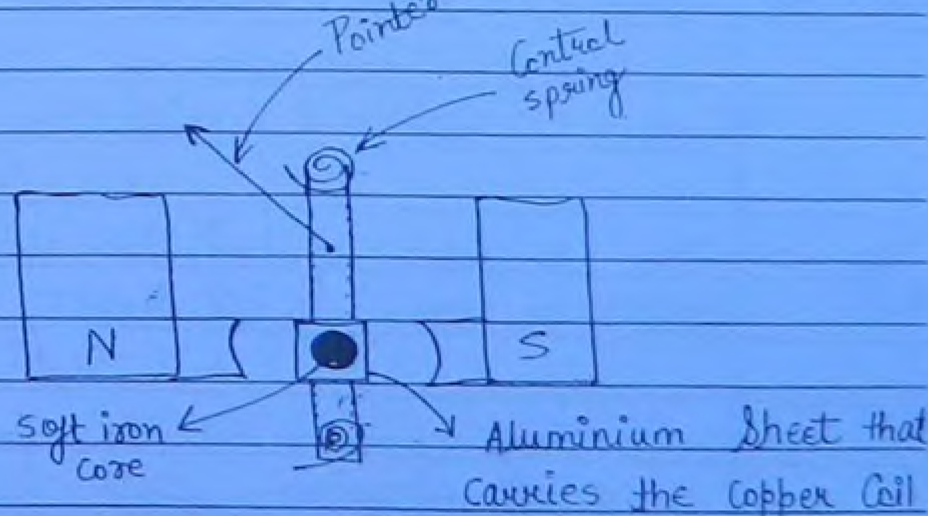
— (iv) Instruments which based their operation of thermoelectric effect of electric current are known as "radiofrequency instruments" and are specially useful for the measurement of current and Voltage at very high frequency.

⟹ PMMC

1. The PMMC instrument utilizes the "magnetic effect of electric current" to produce the deflecting torque.

2. The deflecting torque in this instrument is produced on the basis of the fact that, 'Whenever the current carrying conductor is placed in a magnetic field the conductor experiences a force that tends to push it away from the direction of magnetic field (Fleming's left hand rule).

Construction



Operation:

1. The fixed system of this instrument consists of a permanent magnet and 2 soft iron pole pieces are drilled on to its poles as shown in fig. above.

IES * The permanent magnet is generally made of AL-Ni-co.

PAGE :
DATE : / /

-2. The utility of the soft iron pole pieces is to make the field due to the permanent magnet radial by nature. (18)

-3. The moving system of the instrument consist of a spindle onto which a set of control springs, a soft iron core, an aluminium struct carrying the copper coil and a pointer are mounted.

-4. The moving system is so placed that the aluminium struct and the soft iron core area concentric w.r.t a virtual circle drawn by taking the sectorial surfaces of the soft iron core pieces into consideration.

Imp -5. The control spring in this instrument have a two fold utility:

-(a) They are used to produce a controlling torque.

-(b) They are also used to lead the current into the moving system.

DATE : / /

6. Due to the presence of a strong operating field an eddy current damping mechanism is used to produce the damping torque.

19

7. The mathematical expression that governs the deflecting torque produced in this instrument is given by the expression.

$$\boxed{T_d = NBAI \quad Nm}$$

where,

N = no. of turns of the moving coil.
B = flux density of the permanent magnet in Wb/m^2.
A = Surface area of the coil in m^2
I = Current in Ampere's - through the coil (mA

8. As a spring control mechanism is being used

$$\boxed{T_c = K\theta}$$

and since N, B and A are constant

$$\boxed{T_d = K'I}$$

∴ At steady state position

$$T_c = T_d$$

$$\boxed{\therefore \theta \propto I}$$

Advantages:

-1. As the torque to weight ratio is high, this instrument have a low operational power consumption (25 – 200 μwatt). *Imp P.S.U. Imp (2a)

-2. These instruments gives a larger sensitivity and higher accuracy (±2% of f.s.d). Imp

-3. Due to the presence of a strong operating field these instruments are not easily effected by stray magnetic fields, hence does not require a magnetic shielding.

-4. As $\theta \propto I$, these instruments give a uniform scale.

Disadvantages:

-1. As the direction of the magnetic field of a permanent magnet does not change with the change in the polarity of a.c parameter. These instruments can be used only on D.C.

P.S.U. Note: When the high frequency ac signal is applied to the terminals of the PMMC instrument the pointer would vibrate around the 'zero' position due to its small time period. If a low frequency ac signal is applied to the terminals of (entire of) PMMC instr in that case, the pointer of the instrument would oscillate betn +ve and -ve peaks due to its large time period. (21)

2. As a thin and a light wire is used to wind the moving system the current carrying capacity of these instrument is 'small'. Thin and light wire is used for maintain the high torque to weight ratio.

Note: The maximum current carrying capacity of an optimally designed PMMC instrument is limited to 100 mA. P.S.U.

Sources of Errors:

1. Error's due to the ageing of springs. (These errors are compensated by using a Pre-aged spring in which Pre-ageing is done by subjecting it to mechanical stress).

2. Errors due to the ageing of the permanent magnet.
(These errors are compensated by using a pre-aged permanent magnet, where

Pre-ageing is done by subjecting the magnet (to thermal and Vibrational Stress).

22

-3. Errors due to the change in resistance of the spring and the copper coil due to the heating effect of electric current.

-4 These errors can be compensated as follows:
As the resistance of the copper wire varies negligibly w.r.t temperature due to its low temperature Co-efficient (0.00392/°C) the change in resistance of the copper coil is generally neglected.

-5. The essential characteristics of the spring used as a control mechanism in PMMC instrument are

Imp

- (a) low resistance.
- (b) Small temperature Co-efficient.
- (c) Should not age rapidly
- (d) Should be non-magnetic.

Note: The most Commonly used material for fabricating a control spring in an PMMC instrument is 'Phosphor Bronze'.

Q1. A moving coil of ammeter has 100 turns & length & depth of 10 mm & 20 mm resp. It is positioned in a uniform radial flux density of 200 militesla. If the coil carries a current of 15mA then the torque acting on the coil is ? (23)

Soln:

Continued from pg: 12 :

Note:

(i) The angular ~~displacements~~ deflection of these instruments are proportional to the "R.M.S value of the a.c parameter under measurement".

(ii) These instruments give a "non-uniform scale".

(iii) The Electrodynamometer and Thermo couple type of Instruments are used as a "transfer type" of instrument for calibrating A.C ammeter and Voltmeter.

Gate 2004 (electrical)

Q1. The moving coil of a meter has 100 turns and the length and depth of 10mm and 20 mm resp. If it is positioned in the radial uniform flux density of 200 mTesla and carries a current of 50mA, the torque acting on the coil is

24

Soln

$N = 100$

$B = 200\ mT = 200 \times 10^{-3}\ wb/m^2$

$A = 10\ mm \times 20\ mm = 10 \times 10^{-3} \times 20 \times 10^{-3}\ m^2$

$I = 50mA = 50 \times 10^{-3}\ A$

$\therefore T_d = NBAI\ \ N\text{-}m$

$= 100 \times 200 \times 10^{-3}$

Q2 A PMMC Voltmeter is connected across a combination of a d.c voltage source $V_1 = 2V$, and an a.c voltage source of $V_2(t) = 3 \sin 4t\ V$. The meter reads

Soln: The instrument reads only the dc components. Hence the reading will be 2V.

P.S.U Q3. A 0-5A PMMC Ammeter is supplied with a current of 3A. If the lower control spring of the instr suddenly snaps. The instrument

DATE: / /

will then give a reading of

a) 5A

b) >3 But <5

c) <5

d) 0.1

25

Soln: As the lower control spring snaps there will be a 'Zero' current passing through a moving system, as the Current through the PMMC instrument is lead through the spring. Then the upper Control spring will bring back the pointer back to zero in absence of deflecting torque.

Imp.

Q4) In an PMMC instrument the Control spring Cons and strength of the magnet decrease by 0.04 and 0.02 % resp. due to the rise in temperature by 1°C. With the rise in temperature of 10°C the instrument reading wi

a) ↑ by 0.2%

b) ↓ by 0.2%

c) ↑ by 0.6%

d) ↓ by 0.6%

Soln: We know,

$$\theta = \frac{NBAI}{K} \text{ radians} \quad — (1)$$

1. As the angular deflection of the pointer in an PMMC instrument is directly proportional to the Current. These instruments can be directly used as a Ammeter.

26

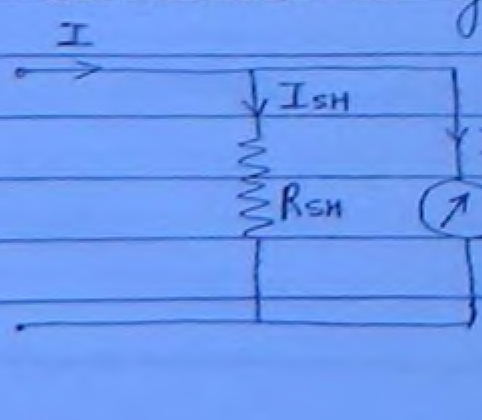
2. But in order to maintain high Torque-to-weight ratio a thin and a light wire was used to wind the moving coil.
This limits the Current carrying capacity of such a instrument.

Imp

3. In order to extent the range of basic PMMC instrument, a low resistance is connected across it.

4. This low resistance is known as the Shunt. resistance bypasses a major portion of Current I through it, thereby protecting it from damage.

5. The value of the shunt resistor R_{SH} is calculated as follows,



In the above ckt,

$$I_{SH} R_{SH} = I_m R_m$$

27

$$\therefore R_{SH} = \frac{I_m R_m}{I_{SH}}$$

$$\boxed{R_{SH} = \frac{I_m R_m}{(I - I_m)}} \quad \text{--- (1)}$$

Taking the reciprocal of eq-(1) and Multiply by R_m on both sides,

$$\therefore \frac{R_m}{R_{SH}} = \frac{(I - I_m) \cancel{R_m}}{I_m \cancel{R_m}}$$

$$\frac{R_m}{R_{SH}} = \frac{I}{I_m} - 1$$

The ratio between I and I_m is known as the "Multiplying Factor" of the shunt denoted by,

$$\boxed{m = \frac{I}{I_m} = 1 + \frac{R_m}{R_{SH}}} \quad \text{--- (2)}$$

Expressing the value of R_{SH} in terms of m.

$$\boxed{R_{SH} = \frac{R_m}{(m-1)}} \quad \text{--- (3)}$$

Note:

The most commonly used material for the fabrication of a shunt resistance is

Maganalim
Constantan
Eureka

28

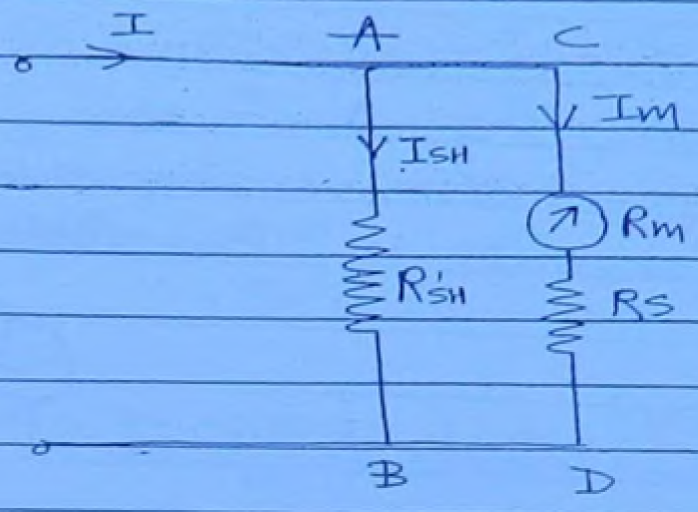
Temperature Compensation in Ammeter circuits:

The errors due to temperature variations in the ammeter circuit occur due to the different rate of change of resistance of shunt and the meter arm.

In Order to compensate the error due to temperature variations a swamping resistance (R_s) is connected along the meter and its magnitude is so choosen such that,

$$R_s \simeq 40 R_m .$$

Mathematical Analysis that describes this compensation is given below,



R_S (swamping resistance)

$R_S \cong 40\, R_m$

$$\frac{\Delta R_{AB}}{R_{AB}} = \frac{\Delta R_{SH}}{R_{SH}}$$

$$\frac{\Delta R_{CD}}{R_{CD}} = \frac{\Delta R_m}{m} + \frac{\Delta R_S}{R_S}$$

As, R_S is very large in Comparison to R_m

$$\frac{\Delta R_{CD}}{R_{CD}} \cong \frac{\Delta R_S}{R_S}$$

as, $\frac{\Delta R_m}{R_m}$ is negligible

Thus if R_S and R_{SH} are made with the same material

$$\frac{\Delta R_{SH}}{R_{SH}} \cong \frac{\Delta R_S}{R_S}$$

or, $$\frac{\Delta R_{AB}}{R_{AB}} \cong \frac{\Delta R_{CD}}{R_{CD}}.$$

Note: The most commonly used material for fabrication of shunt and swampping resistance in temperature compensated ammeter is "Mangaldnin".

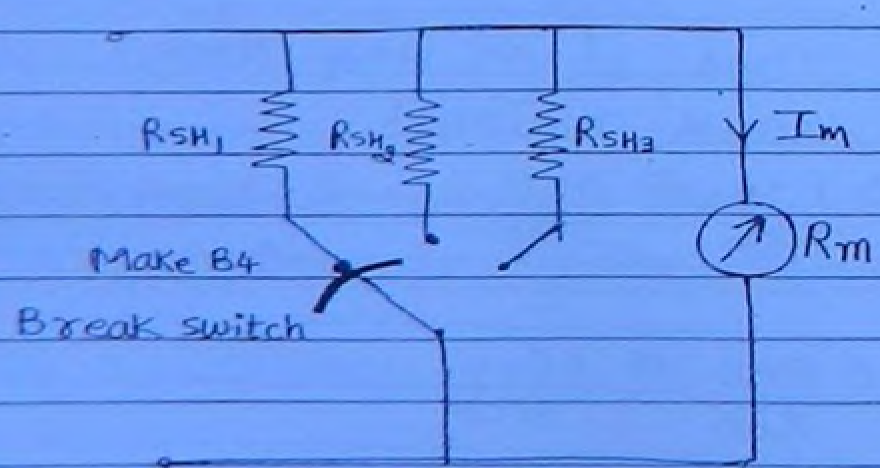
30

Ammeter With Multiple Ranges:

Multiple ranges in an ammeter ckt. are incorporated by 2 design methodologies

1. Multi range ammeter method
2. Ayrtons Shunt or Universal shunt method.

1. Multi-Range Ammeter Method.



DATE : / /

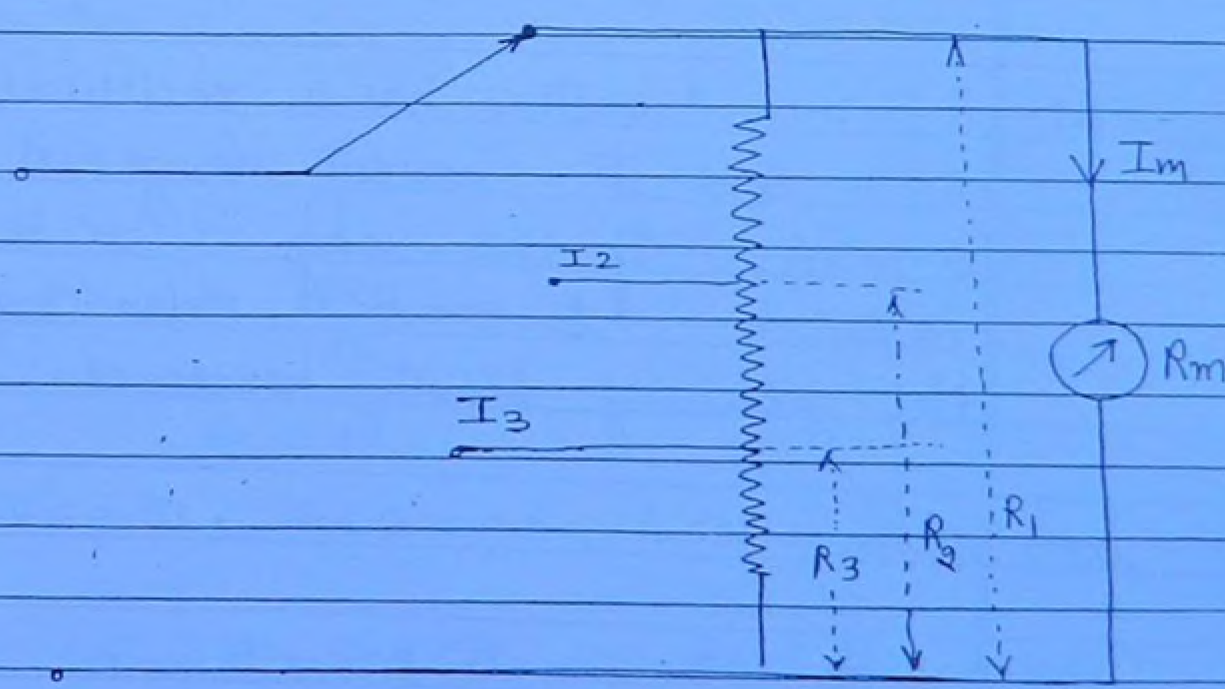
$$R_{SH_1} = \frac{R_m}{(m_1 - 1)} \quad ; \quad m_1 = \frac{I_1}{I_m}$$

3

$$R_{SH_2} = \frac{R_m}{(m_2 - 1)} \quad ; \quad m_2 = \frac{I_2}{I_m}$$

$$R_{SH_3} = \frac{R_m}{(m_3 - 1)} \quad ; \quad m_3 = \frac{I_3}{I_m}$$

2. Universal shunt Method:



R_1

1. In a Multi ammeter method, a make B4 break type of switch is used in order to protect the meter movement from the total current under measurement during switch transition. 32

2. In Ayrton's shunt method, the meter ends up giving a higher meter resistance at all positions except the switch position 1.

Q1. A D.C Ammeter has a resistance of 0.1 Ω and its current range is 0-100 A. If the range is to be extended to 500 A, Meter requires the following shunt resistance.

Soln: $I_m = 100\,A$, $R_m = 0.1\,\Omega$, $I = 500\,A$.

$$m = \frac{I}{I_m} = \frac{500}{100} = 5$$

$$\therefore R_{SH} = \frac{R_m}{(m-1)} = \frac{0.1}{5-1} = \frac{0.1}{4}$$

$$\therefore R_{SH} = 0.025\,\Omega$$

Q2) A 100 µA ammeter has an internal resistance of 100 Ω. For extending its range to measure 500 µA the shunt required is of resistance.

Soln:
$$\frac{I}{I_m} = 1 + \frac{R_m}{R_{SH}}$$

$$\Rightarrow 5 = 1 + \frac{100}{R_{SH}} \Rightarrow \frac{100}{R_{SH}} = 4 \Rightarrow R_{SH} = 25\,\Omega$$

Q3 The PMMC instrument with the full scale Current of 10 mA as a resistance of 1000 Ω the multiplying power for a 100 Ω shunt with this is

Soln:
$$R_{SH} = \frac{R_m}{(m-1)}$$

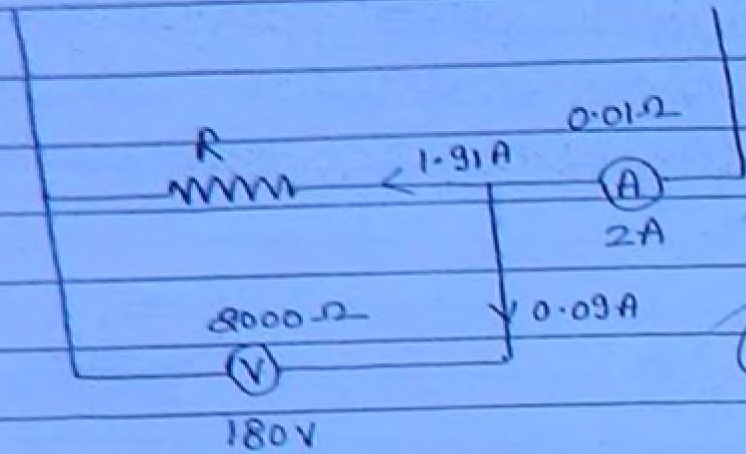
$$(m-1) = \frac{1000}{100}$$

$$= 10 + 1$$

$$m = 11$$

Q4) The Set-up in the fig is used to measure resistance R. The ammeter and voltmeter resistance are 0.01 Ω and 2000 Ω resp. Their reading are 2A and 180V resp. giving a measured If the true value of the resistance is 90 Ω The % error in its measurement is.

Soln:



34

$$I_V = \frac{180}{2000} = 0.09A$$

$$I_R = 2 - 0.09$$
$$= 1.91A$$

$$R = \frac{V}{I_R}$$
$$= \frac{180}{1.91}$$

$$\therefore R = 94.24\,\Omega$$

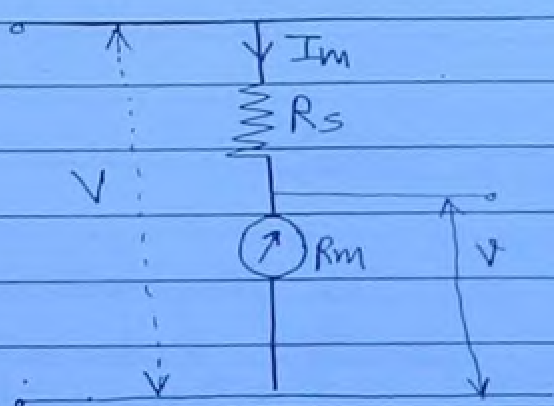
$$\%\ \text{Error} = \frac{94.24 - 90}{90} \times 100$$

$$= 4.7\%$$

Imp (35) The basic PMMC movement is modified as a Voltmeter by connecting a high resistance in series with the meter.

This high resistance known as the Multiplier resistance, limits the current passing through the meter movement, thereby protecting it from damage.

The value of Multiplier resistance Rs is Calculated as follows,



We have,

$$v = I_m R_m$$

$$V = I_m (R_s + R_m)$$

$$V = I_m R_m + I_m R_s$$

$$R_s = \frac{V}{I_m} - R_m \qquad \text{——— (1)}$$

'm' is the multiplying factor of the Multiplier can be expressed as,

$$m = \frac{V}{v}$$

$$= \frac{I_m (R_m + R_s)}{I_m R_m}$$

$$= \frac{R_m + R_s}{R_m}$$

$$= 1 + \frac{R_s}{R_m} \quad \text{——} \; (2)$$

36

Expressing R_s in terms of m

$$R_s = (m-1) R_m \quad \text{——} \; (3)$$

⇒ **Temperature Compensation:**

- (i) Errors due to temperature variation in Voltmeter occur due to the change in resistance of the Multiplier resistor due to the heating effect of the electric Current.

- (ii) Thus if the Multiplier resistance is fabricated with a material that has a negligible temperature Co-efficient, then these errors can be compensated.

Note: Multiplier resistances in a Voltmeter ckt are generally fabricated by

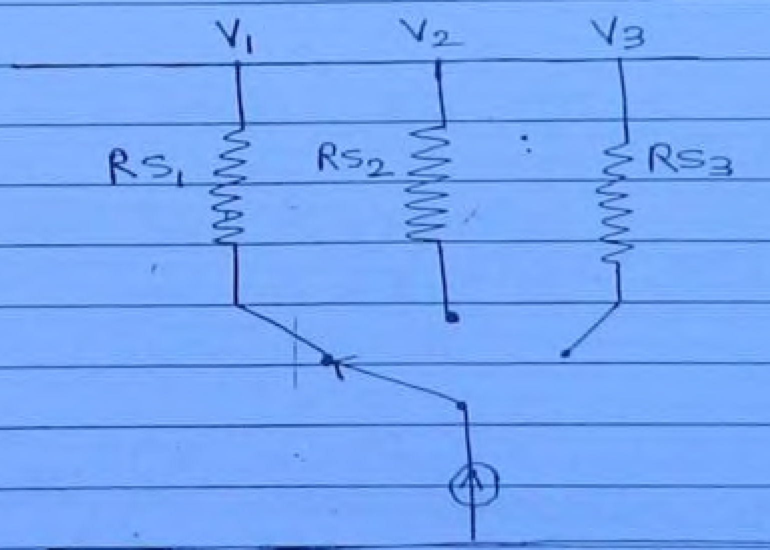
'Mauglanin'.

Multiple Ranges in a Voltmeter Circuit:

Like the PMMC Ammeter 2 distinctively different design methodologies can be used to incorporate multiple ranges in a Voltmeter Circuit.

1. The Individual Multiplier method.
2. The Potentiometer Method.

1. Individual Multiplier Method:

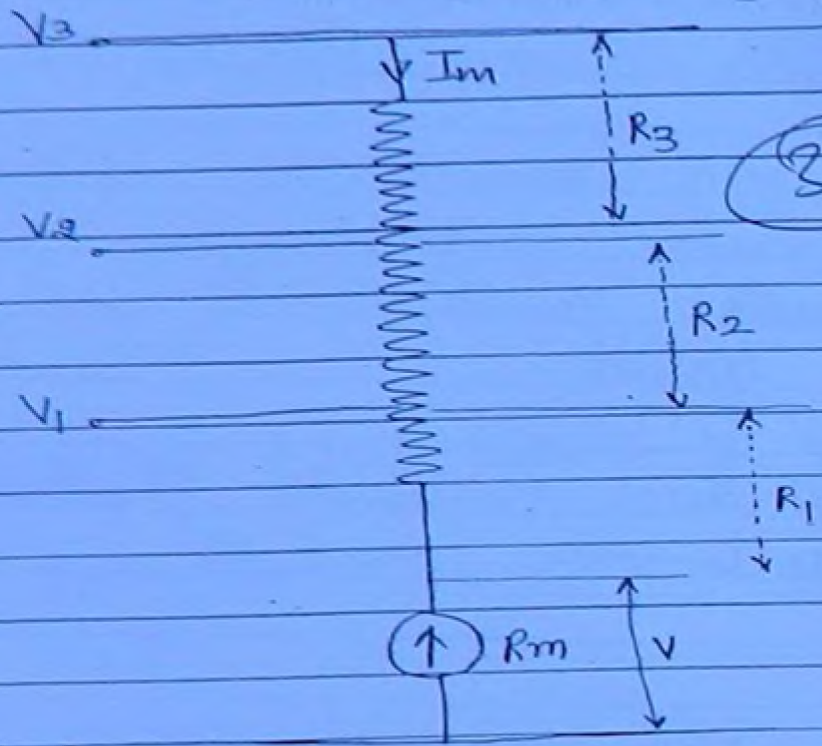


$$R_{S_1} = (m_1 - 1) R_m \quad ; \quad m_1 = \frac{V_1}{V}$$

$$R_{S_2} = (m_2 - 1) R_m \quad ; \quad m_2 = \frac{V_2}{V}$$

$$R_{S_3} = (m_3 - 1) R_m \quad ; \quad m_3 = \frac{V_3}{V}$$

2. Potentiometer Method:



38

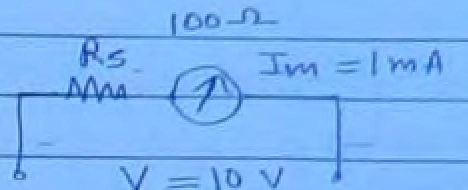
$R_1 = (m_1 - 1) R_m$; $m_1 = \frac{V_1}{V}$

$R_2 = (m_2 - m_1) R_m$; $m_2 = \frac{V_2}{V}$

$R_3 = (m_3 - m_2) R_m$; $m_3 = \frac{V_3}{V}$

Q1. A PMMC instrument with an internal resistance R is equal to 100 Ω and full scale Current of 1 mA is to be Converted into 0-10 Voltmeter, what is the required resistance.

Soln:



$$V = (R_s + R_m) I_m$$

$$\frac{10}{1mA} = R_s + R_m$$

39

$$R_s = 10^4 - R_m$$

$$= 10^4 - 100$$

$$= 10000 - 100$$

$$R_s = 9900\,\Omega$$

Q2. For the Voltmeter CKt. shown in the figure, the basic PMMC meter used has a full scale current of 1mA and meter resistance of 100 Ω. The values of R_1 and R_2 required for the 10V range and the 50V range will be

Soln

$I_m = 1mA$, $R_m = 100\,\Omega$

$$10 = I_m (R_1 + R_2 + 100)$$

$$10^4 = (R_1 + R_2 + 100)$$

or, $R_1 + R_2 = 9900\,\Omega$ —— (1).

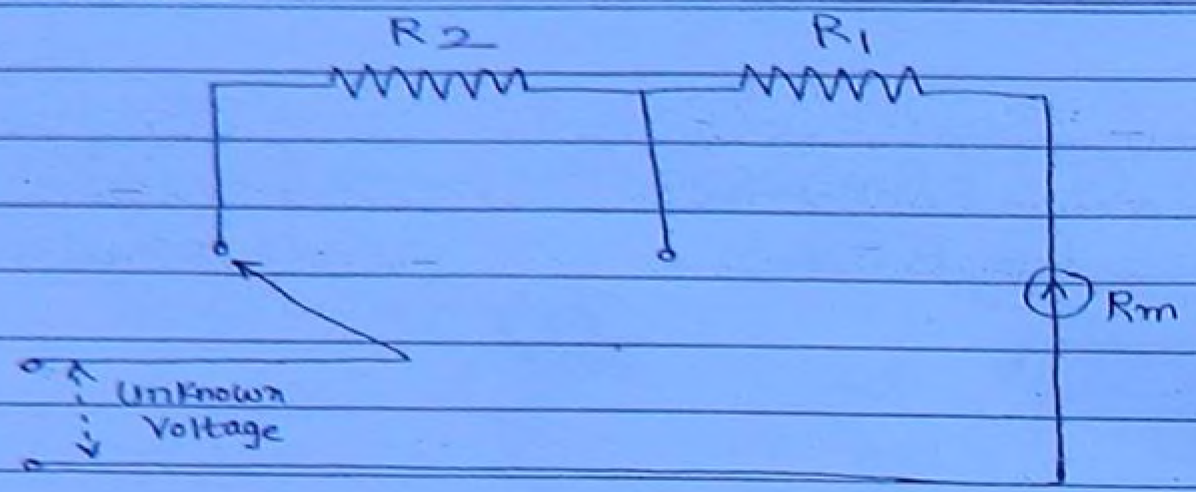
$$\frac{50}{10^{-3}} = (R_1 + R_2 + 100)$$

$$50 \times 10^3 - 100 = R_1 + R_2$$

$$R_1 + R_2 = 9900$$

$$R_1 + R_2 \quad 49900$$

Soln:



$R_1 = (m_1 - 1) R_m$

40

$m_1 = \frac{10}{0.1} = 100$

$R_1 = (100 - 1) R_m$

$= 99 \times 100$

$= 9.9K$

$R_2 = (m_2 - m_1) R_m$ $\qquad m_2 = \frac{V_2}{v} = \frac{50}{0.1} = 50$

$= (500 - 100) \times 100$

$= 400 \times 100$

$\therefore R_2 = 40K$

p.s.u

Sensitivity of Voltmeter

The Sensitivity of a voltmeter is defined as the resistance of the voltmeter for a single volt range.

Mathematically expressed as,

$$\boxed{S_V = \frac{R_T}{V} \quad \Omega/V}$$

$$R_T = R_m + R_s$$

$$S_V = \frac{R_m + R_s}{I_m (R_m + R_s)}$$

$$\boxed{\therefore S_V = \frac{1}{I_m} \quad \Omega/V}$$

Q1. Which one of the following meters is more sensitive than the other and why?

p.s.u

1. Voltmeter A with a range of 0–10 V and a Multiplier resistance of 18 KΩ.

2. Voltmeter B with a range of 0–300 V and a Multiplier resistance of 298 KΩ.

Note: both the meters have an internal resistance of 2 KΩ

A	B
$R_S = 18\,K$	$R_S = 298\,K$
$R_m = 2\,K$	$R_m = 2\,K\Omega$
$R_T = 20\,K$	$R_T = 300\,K\Omega$
$V = 10$	$V = \cancel{10}\,300$
$\therefore S_v = 2\,K\Omega/V$	$S_v = 1\,K\Omega/V$.

42

→ From above analysis it can be said that meter A requires $\frac{1}{2}$ the current required by B to produce full scale deflection.

Hence A is more sensitive than meter B.

Q2) A dc voltmeter has a sensitivity of $1000\,\Omega/V$. When it measures half full scale ~~limits~~ in its 100 V range, the current through the voltmeter is

$$S_v = \frac{R_T}{V}$$

$$R_T = S_v \cdot V$$

$$= 1000 \times 100$$

$$\therefore R_T = 100 \times 10^3\,\Omega$$

$$I_m = \frac{V}{R_T} = \frac{50}{100 \times 10^3} = 0.5\,mA$$

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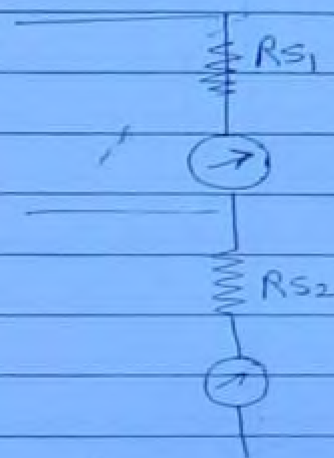
Q3) 2 100V PMMC type DC Voltmeters having figure of merits of 10 kΩ/V and 20 kΩ/V are connected in series. The series Combination can be used to measure a max. dc voltage of ___ V.

(43)

Soln :



$S_{V_1} = 10\ k\Omega/V$

$S_{V_2} = 20\ k\Omega/V$

$S_{V_1} = \frac{R_T}{V}$

$R_T = S_{V_1} \times V$

$= \frac{10\ k\Omega}{V} \times 100\ V$

$R_{T_1} = 1000 \times 10^3\ \Omega$

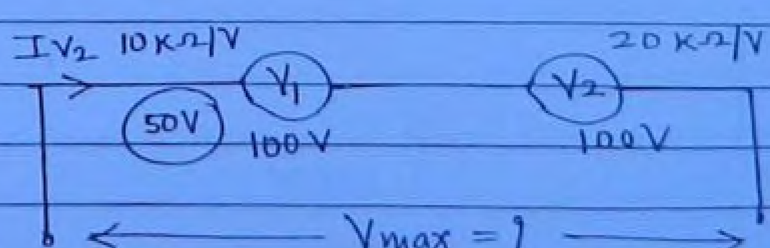
Similly, $R_{T_2} = S_{V_2} \times V$

$= \frac{20\ k\Omega}{V} \times 100\ V$

$R_{T_2} = 2000 \times 10^3\ \Omega$

$R_T = R_{T_1} + R_{T_2}$

$R_T = 3000\ k\Omega$



$V_{max} = 100 + 50$

$= 150\ V$

from the above figure it can be seen that the max. current this combination can carry is the full scale deflection of current of voltmeter 2 as it requires half the current required by voltmeter 1 to produce full scale deflection.

Thus, if V_2 shows the full scale deflection, V_1 will be indicating half of full scale.

$\therefore$ The Max. vltg this series can measure is 150 V.

Q4) 3 dc voltmeters are connected across a 120 V dc supply. The voltmeters are specified as follows.

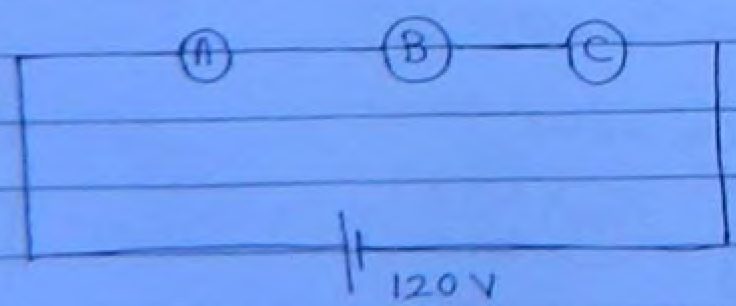
Voltmeter A 100 V, 5 mA

Voltmeter B 100 V, 250 Ω/V

Voltmeter C 10 mA, 15000 Ω

The voltages read by voltmeter A, B & C are respectively.

Soln



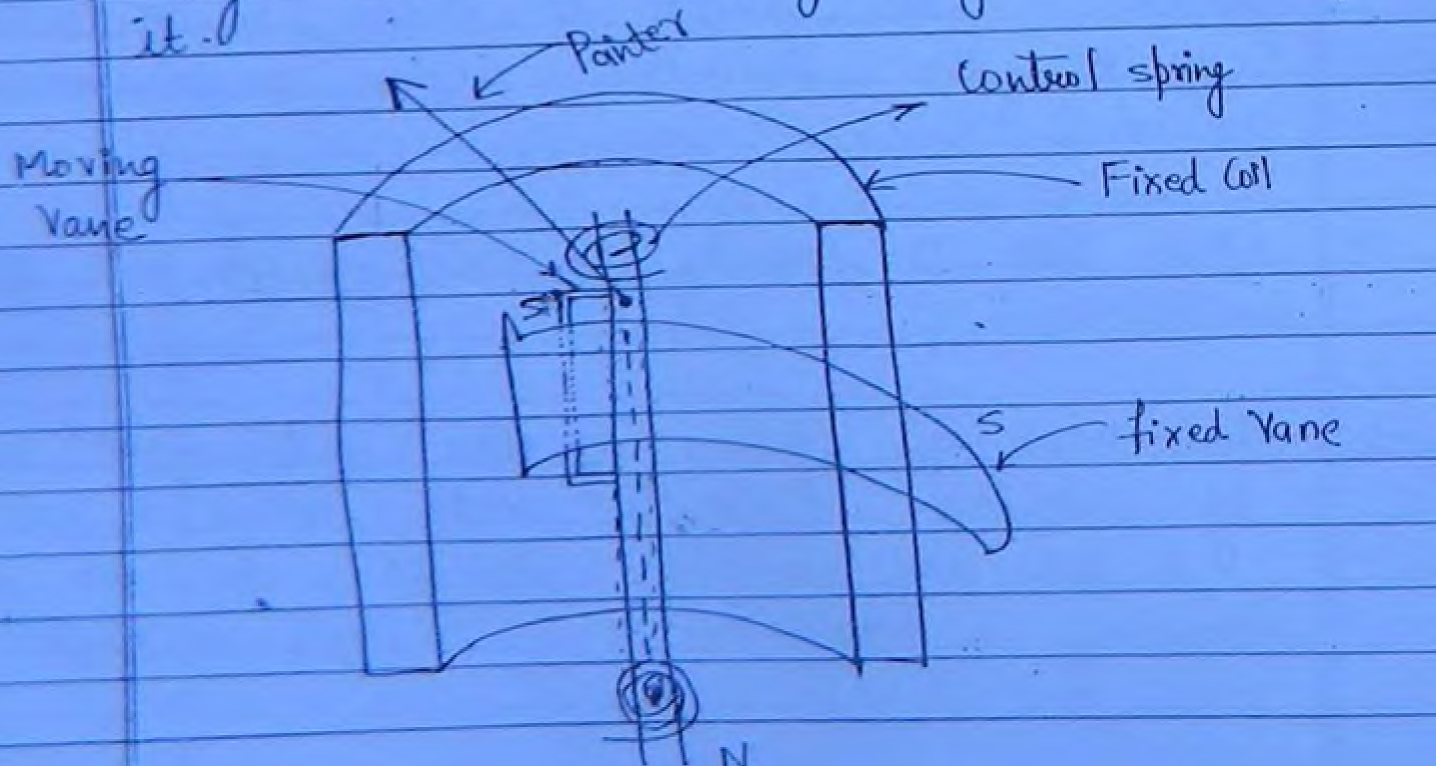
$R_n =$ 43

moving vane are mounted.

5. In order to increase the span of the instrument the moving system is mounted eccentrically (away from the centre) w.r.t central axis of the fixed coil.

Repulsion type of Instrument:

1. The deflecting torque in this instrument is produced because of the force of repulsion between the fixed and the moving vanes due to the similar polarities induced on them by the magnetic field of the fixed coil, resulting ~~fe~~ because of the current flowing through it.



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-2. The fixed system of this instrument consist of a C-shaped insulating former on which a thick coil which carries a current under measurement is wound (49)

-3. Known as the fixed coil it has a small soft iron vane non-magnetically cemented on it.

-4. The Moving system of this instrument consist of a spindle onto which a pointer, a set of control springs, an air friction damping mechanism and a soft iron vane are mounted as shown in the fig.

-5. The moving system in this case is placed concentrically w.r.t the central axis of the fixed coil as shown in the fig.

→ The controlling torque in this instrument is produced by a spring control mechanism and the damping torque is produced by an air friction damping mechanism as the magnetic field due to the electromagnet is weak.

→ The generalized expression for the deflecting

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torque of the moving iron type of instrument is given as.

$$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta} \quad N\text{-}m .$$

As a spring control mechanism is used we have,

$$T_c = K\theta .$$

At steady state position

$$T_c = T_d$$

$$\therefore K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

$$\theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta} \quad rad$$

$$\therefore \theta \propto I^2$$

Advantages:

1. As the direction of the magnetic field in this instrument changes with change in polarity of ac parameter under measurement these instruments can be used for both a.c and d.c.

2. As the current under measurement in these

instrument passes through a fixed coil. These instruments have the capability to carry a large amount of Current.

(5)

3. As the Current is being passed through the fixed coil of the instrument. These instrument have a larger Current carrying capacity.

Note: Moving Coil ammeters upto a range of 50A can be designed without the use of a shunt

4. As the instrument exhibits a square law response the angular deflection of these instruments is directly interms of R.M.S value of the ac parameter under measurement.

Disadvantages:

1. As the compensation required for these instruments is different for both ac & dc these instruments have a different Calibration for both ac and dc parameters.

Imp

Note: P.S.U

An M.I type of Instrument Calibrated on a.c if used on d.c will be over Compensated for errors and hence will give a higher reading.

Simillarly,

An M.I type of instrument calibrated on d.c if used on a.c will be under-compensated for errors and hence will give a lower reading. (52)

- 2. As the magnetic field due to the electromagnet is weak, these instruments are easily affected by stray magnetic field and hence require 'magnetic shielding'.

- 3. As $\theta \propto I^2$, these instruments have a non-uniform scale

Sources of Errors:

- 1. Error due to the ageing of the spring. (Both a.c and d.c).

- 2. Error due to the change in resistance of the copper coil because of the heating effect of the electric current. (Both a.c and d.c).

- 3. Errors due to Eddy Currents - These errors are eliminated by using a thick Multi-Standard wire to wind the fixed coil. (only for a.c)

4. Errors due to Hysterisis – These errors are compensated by decreasing the surface area of the soft iron vane (only for a.c)

53

5. Errors due to frequency – The errors due to frequency in an M.I instrument occur due to the inductive reactance of the coil and also due to the "Harmonics" present in the i/P.

Errors due to the inductive reactance can be compensated by introducing a proportional capacitive reactance into the system but, the errors due to the Harmonic components are neglected.

Q1. A moving iron ammeter produces a full scale torque of 240 μN-m with the deflection of 120° at a current of 10A. The rate of change of self inductance of an instrument at the full scale will be.

Soln:

$$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta} \quad \mu N\text{-}m$$

$$\therefore \frac{dL}{d\theta} = \frac{T_d}{\frac{1}{2} I^2} = \frac{240 \times 10^{-6}}{\frac{1}{2} \times 100}$$

$$= \frac{480}{100} \times 10^{-6}$$

$$\frac{dL}{d\theta} = \underline{4.8 \times 10^{-6}} \text{ H/radian or } \underline{4.8 \ \mu H/\text{radian}}$$

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Q.2 The inductance of a certain moving iron ammeter is given as

$$L = \left(10 + 3\theta - \frac{\theta^2}{4}\right) \mu H$$

(54)

Where,

θ = deflection in radian from zero position.

If the control spring constant of the instrument is 25×10^{-6} N-m / radian. The deflection of the pointer in radian when the meter causes the current of 5A is .

Soln:

$$\frac{dL}{d\theta} = \left(3 - \frac{\theta}{2}\right) \times 10^{-6} \text{ Henry/radian}$$

$$\therefore \theta = \frac{1}{2} \frac{I^2}{K} \cdot \frac{dL}{d\theta}$$

$$= \frac{1}{2} \cdot \frac{\cancel{25}}{\cancel{25} \times \cancel{10^{-6}}} \times \left(3 - \frac{\theta}{2}\right) \times \cancel{10^{-6}}$$

$$2\theta = 3 - \frac{\theta}{2}$$

or, $\frac{5\theta}{2} = 3$

$$5\theta = 6$$

$$\theta = \frac{6}{5}$$

$$\therefore \theta = 1.2$$

Imp Conv (12 mks)

Expression for the deflecting torque of a moving iron type of instrument.

55

The expression for the deflecting torque of M.I type of instrument is derived by taking the law of Conservation of energy into Consideration and is analysed by the energy relations associated with the system.

Initial Conditions:

(i) Initial Current is I

(ii) Deflection is θ

(iii) Inductance of Coil is L

If an incremental current (dI) is supplied to the system, then the depletion changes by ($d\theta$) and some mechanical work will be done.

If T_d is the deflecting torque, then the mechanical work done can be expressed as,

$$\boxed{\text{Mechanical Work done} = T_d \cdot d\theta} \quad \text{—— (1)}$$

As the incremental Current (dI) is supplied to the system the deflection changes by $d\theta$ and the inductance changes by dL that is,

Initial Current I changes by dI

Inductance L changes by dL

deflection θ changes by $d\theta$

The emf can be expressed as,

$$e = \frac{d}{dt}(LI)$$

$$= L\frac{dI}{dt} + I\frac{dL}{dt}$$ (56)

Electrical i/p energy can be expressed as,

$$\boxed{eI\,dt = IL\,dI + I^2 dL}$$ — (2)

Energy stored in magnetic field is given by,

$$\frac{1}{2}I^2L$$

Energy changes to $\frac{1}{2}(I+dI)^2(L+dL)$

The change in energy stored will be

$$\boxed{\frac{1}{2}(I+dI)^2(L+dL) - \frac{1}{2}I^2L}$$ —

Simplifying the above eq^n and neglecting the higher order terms we have,

$$\boxed{IL\,dI + \frac{1}{2}I^2 dL}$$ — (3)

From the law of Conservation of energy, we have electrical i/p energy is equal to change in the energy stored plus the mechanical work done.

$$I^2 dL + IL\,dI = \frac{1}{2} I^2 dL + IL\,dI + T_d \cdot d\theta$$

57

$$\frac{1}{2} I^2 dL = T_d \cdot d\theta$$

$$\boxed{T_d = \frac{1}{2} I^2 \frac{dL}{d\theta} \ N\text{-}m}$$

As a spring control mechanism is used.

$$\boxed{T_c = K\theta}$$

At steady state position we have,

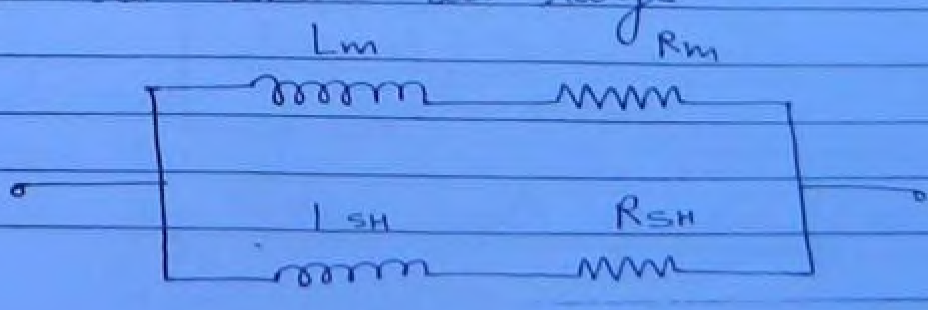
$$\boxed{K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}}$$

or,
$$\boxed{\theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}}$$

Applications of M.I Instruments:

1. **M.I Ammeters:**

If the range of an M.I instrument is to be extended beyond 50 A then a shunt is connected across the M I instrument in order to extend its range.

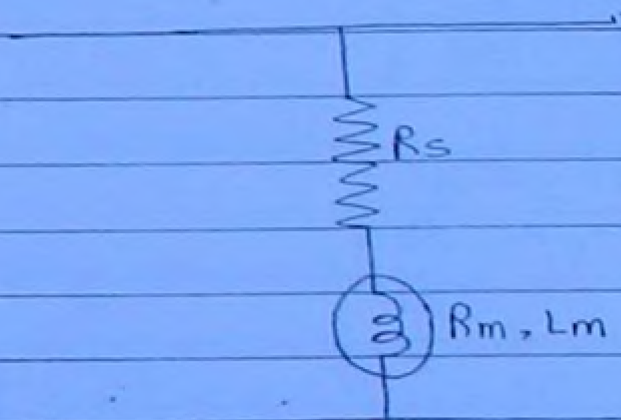


$$R_{SH} = \frac{R_m}{(m-1)} \quad ; \quad m = \frac{I}{I_m}$$

If the instrument is to be used at all frequencies then the time constant of both the shunt and the meter arms are made equal.

$$\boxed{\frac{L_m}{R_m} = \frac{L_{SH}}{R_{SH}}}$$

2. M.I type of Voltmeters:



$$R_s = (m-1) R_m \quad ; \quad m = \frac{V}{v}$$

$$m = \frac{I_m (R_s + R_m + j\omega L_m)}{I_m (R_m + j\omega L_m)}$$

$$\boxed{\therefore m = \frac{\sqrt{(R_m + R_s)^2 + (\omega L_m)^2}}{\sqrt{R_m^2 + (\omega L_m)^2}}}$$

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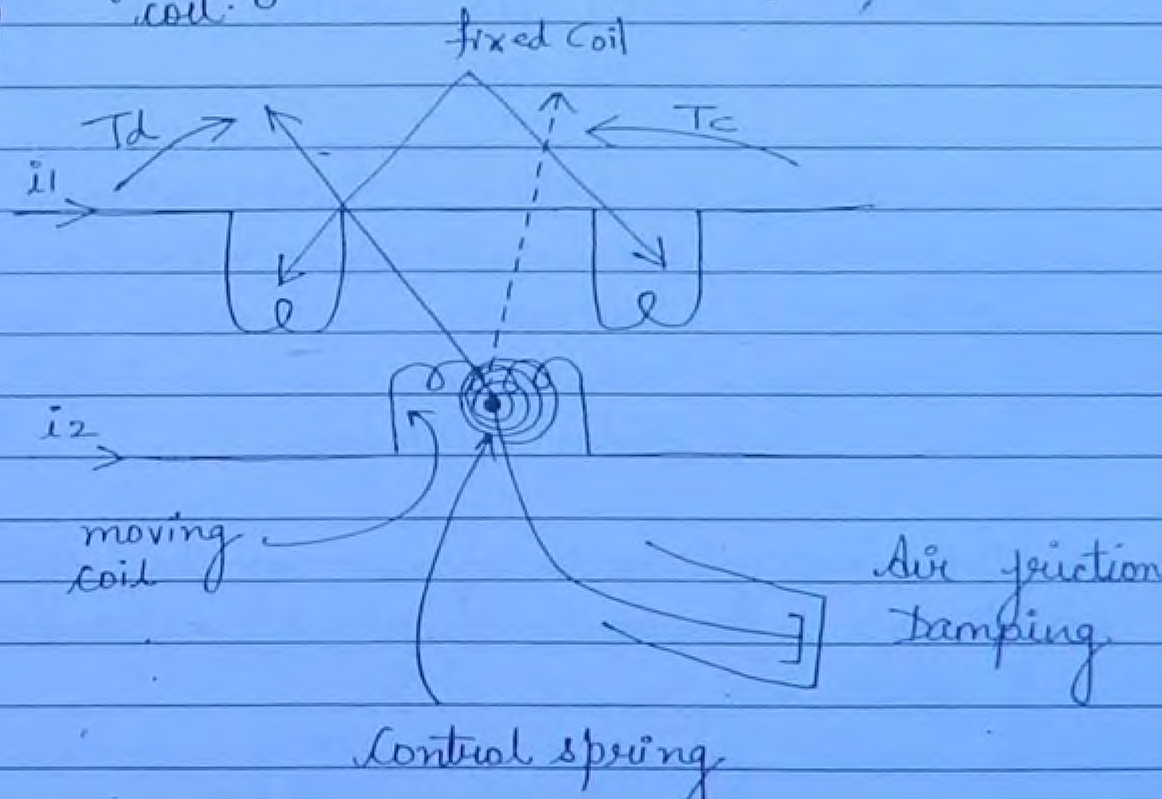
Electrodynamometer Type of Instrument :

-1. The electrodynamometer type of instrument bases its operation on the magnetic effect of electric current.

-2. The deflecting torque in this instrument is produced due to the interaction of the current flowing through the fixed and moving coil.



-3. The fixed system of this instrument consist of a fixed coil which is air cored and mount with a thick Multi standard wire for a small number of turns.

-4. The fixed coil is split into 2 parts in order to focus the flux due to the fixed coil inbetween the two parts of the fixed coil.

5. The moving system of the instrument consist of a spindle onto which a pointer, a set of Control springs, an air friction damping mechanism and a moving coil are mounted.

(60)

6. The entire moving system of the instrument is so placed such that the moving coil comes in between the two parts of the fixed coil.

7. A spring control mechanism is used to produce the controlling torque in this instrument. whereas, an air friction damping mechanism is used to produce the damping torque.

8. The instantaneous value of the deflecting torque produced in this instrument is given by

$$\boxed{T_i = i_1 i_2 \frac{dM}{d\theta}} \quad N\text{-}m$$

Where,

i_1 and i_2 are the instantaneous Value of the Current flowing through the fixed and moving Coil.

Advantages:

-1. These instrument give a precision grade accuracy upto a frequency of 10 KHz.

-2. As the Calibration for both a.c and d.c of these instrument are same they can be used as transfer type of instrument for calibrating M.I type a.c ammeter's and Voltmeters.

-3. These instruments have a large number of applications and can be modified to work as Ammeters, Voltmeters, Wattmeters, Varmeters, Power factor meters and frequency meters.

Note:

-(i) The most common application of an electro-dynamo meter type of instrument is 'Wattmeter'

-(ii) The electrodynamometer type of Power factor meter is an instrument in which no controlling torque is produced due to the absence of the controlling mechanism.

-4. As $\theta \propto I_1 I_2$ the angular deflection of these instrument is directly in terms of the r.m.s value of the a.c parameter under measurement.

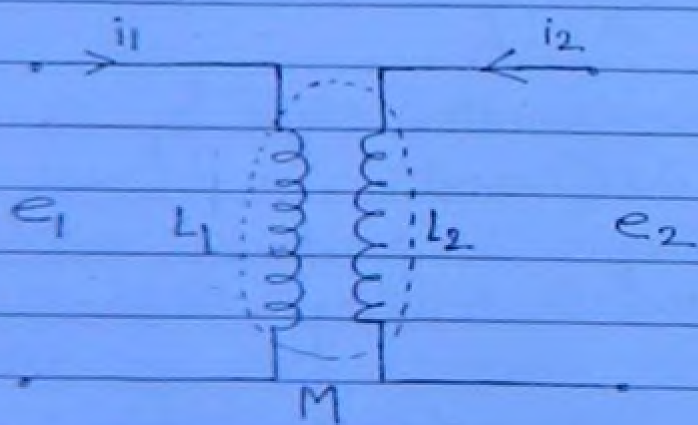
Disadvantages:

-1- Due to the presence of the weak operating flux, the torque to weight ratio of the instrument is low resulting in the lower sensitivity

-2- These instruments have a non-uniform scale as $\theta \propto I_1 I_2$

→ Expression for the deflecting torque of an Electrodynamometer type of Instrument:

The expression for the deflecting torque of an electro dynamo meter of Instrument is based on " law of Conservation of energy and is derived by takeng the energy relationship of the system into Consideration.



In the above figure we have

i_1 = Instantaneous value of current through the fixed coil in Amperes.

i_2 = instantaneous value of the Current through the moving coil in Amperes

63

L_1 = Self inductance of the fixed coil in Henry

L_2 = Self inductance of the moving coil in Henry

M = Mutual inductance between the fixed and the moving coils in Henry.

From the above fig. we have flux linkages of the fixed coil

$$\boxed{\psi_1 = L_1 i_1 + M i_2}$$

Similarly,

Flux linkage due to moving coil will be,

$$\boxed{\psi_2 = L_2 i_2 + M i_1}$$

Now,

Electrical i/p energy can be written as

$$\boxed{e_1 i_1 dt + e_2 i_2 dt}$$

As,

$$e_1 = \frac{d\psi_1}{dt} \text{ and } e_2 = \frac{d\psi_2}{dt}$$

$\therefore$ Electrical i/p energy $= i_1 \frac{d\psi_1}{dt}.dt + i_2 \frac{d\psi_2}{dt}.dt$

$$\boxed{\text{Electrical i/p energy} = i_1 d\psi_1 + i_2 d\psi_2}$$

$$= i_1\, d(L_1 i_1 + M i_2) + i_2\, d(L_2 i_2 + M i_1)$$

64

$$\left.\begin{aligned} &= i_1 L_1\, di_1 + i_1^2\, dL_1 + i_1 i_2\, dM + i_1 M\, di_2 \\ &+ i_2 L_2\, di_2 + i_2^2\, dL_2 + i_1 i_2\, dM + i_2 M\, di_1 \end{aligned}\right\} \quad \text{--- (1)}$$

Now,

Energy stored in the magnetic field is given by,

$$\boxed{\frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M}.$$

$\therefore$ change in energy stored can be expressed as,

$$= d\left(\frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M\right)$$

$$= \frac{i_1^2}{2}\, dL_1 + i_1 L_1\, di_1 + \frac{i_2^2}{2}\, dL_2 + i_2 L_2\, di_2 + i_1 i_2\, dM$$

$$+ i_1 M\, di_2 + i_2 M\, di_1 \quad \text{--- (2)}$$

From the law of Conservation of energy we have,

electrical i/p energy = change in energy stored + Mechanical work done.

So, The Mechanical work done can be accessed from the difference of electrical i/p energy and the change in energy stored.

$\therefore$ The mechanical work done will be,

$$\boxed{= \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 \, dM}$$

If T_i is the instantaneous torque developed then the above expression can be written as

$$\boxed{T_i \, d\theta = \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 \, dM}.$$

As L_1 and L_2 are constant,
dL_1 and $dL_2 = 0$.

Hence

$\therefore T_i \, d\theta = i_1 i_2 \, dM$

or $$\boxed{T_i = i_1 i_2 \frac{dM}{d\theta} \quad N\text{-}m}$$

1. For dc parameters:

$i_1 = I_1$, the Current through fixed coil.
$i_2 = I_2$; the Current through moving coil.

$$\boxed{\begin{array}{l} \therefore T_d = I_1 I_2 \dfrac{dM}{d\theta} \quad N\text{-}m \\ \text{or} \quad \theta = \dfrac{I_1 I_2}{K} \dfrac{dM}{d\theta} \quad rad \end{array}}$$

2. For ac parameters:

The average deflecting torque in an entire cycle can be expressed as,

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$$\boxed{\begin{aligned} T_{av.} &= \frac{1}{T}\int_0^T T_i \, dt \\ T_{av} &= \frac{1}{T}\frac{dM}{d\theta}\int_0^T i_1 i_2 \, dt \end{aligned}}$$

6

v. imp

3. For Sinusoidal Currents:

$i_1 = I_{m_1} \sin\omega t$
$i_2 = I_{m_2} \sin(\omega t - \phi)$.

$$\therefore T_d = \frac{1}{T}\frac{dM}{d\theta}\int_0^T I_{m_1} \sin\omega t \cdot I_{m_2} \sin(\omega t - \phi) \, d(\omega t).$$

$$= \frac{1}{T} I_{m_1} \cdot I_{m_2} \cdot \frac{dM}{d\theta}\int_0^T \sin\omega t \cdot \sin(\omega t - \phi) \, d(\omega t).$$

$$= \frac{I_{m_1} \cdot I_{m_2}}{2} \cos\phi \, \frac{dM}{d\theta}.$$

$$\boxed{\therefore T_d = \frac{I_{m_1}}{\sqrt{2}} \cdot \frac{I_{m_2}}{\sqrt{2}} \cos \widehat{\frac{I_{m_1}}{\sqrt{2}} \; \frac{I_{m_2}}{\sqrt{2}}} \, \frac{dM}{d\theta}.}$$

$$\boxed{\therefore T_d = I_1 I_2 \cos \widehat{I_1 \, I_2} \, \frac{dM}{d\theta} \; \text{N-m}}$$

Measurement of Power.

→ Power in D.C cKts PSU

→ Power in A.C cKts (GT)

↳ Electrodynamometer Wattmeter. conv/IES

↳ Errors in Wattmeters. IES/PSU/conv/obj

↳ Low power factor Wattmeter. PSU

→ Power in Polyphase cKt ES/PSU/conv/obj

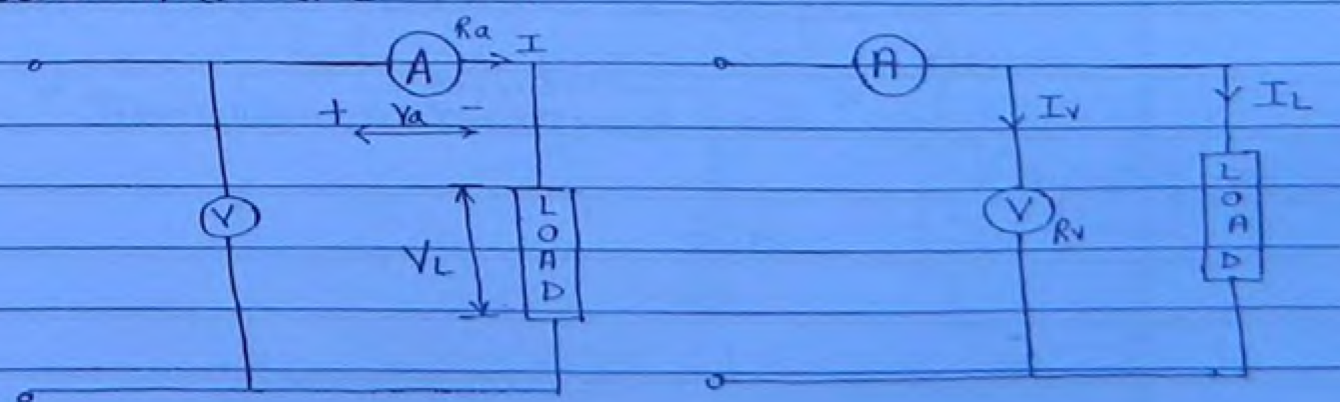
↳ Blondels Theorem.

Measurement of power in D.C cKts:

Power in a d.c circuit is given as the product of the Current and the voltage.

Thus a simple Voltmeter – Ammeter Combination would be one of the most efficient method for the measurement of power in a d.c. cKt.

The 2 fig. shown below are the possible methodology of connecting of a voltmeter and an ammeter for the measurement of power in a d.c cKts.



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$$P = VI$$
$$= I(V_a + V_L)$$
$$= I(IR_a + V_L)$$
$$\therefore P = I^2 R_a + IV_L$$

68

$$P = VI$$
$$= V(I_v + I_L)$$
$$= V\left(\frac{V}{R_v} + I_L\right)$$
$$\therefore P = \frac{V^2}{R_v} + VI_L$$

-1. In fig.1 when the ammeter is connected on the load side, the reading of the Voltmeter would contain the sum of the voltage drop across the load as well as the ammeter

-2. from above analysis it can be seen that the calculated power in this case would not only contain a component of the power dissipated by the load but would also contain a component of the power loss in the ammeter circuit.

-3. As the power loss in the ammeter circuit varies as the square of the load Current this connection methodology would be suitable for in instances were load Current is small.

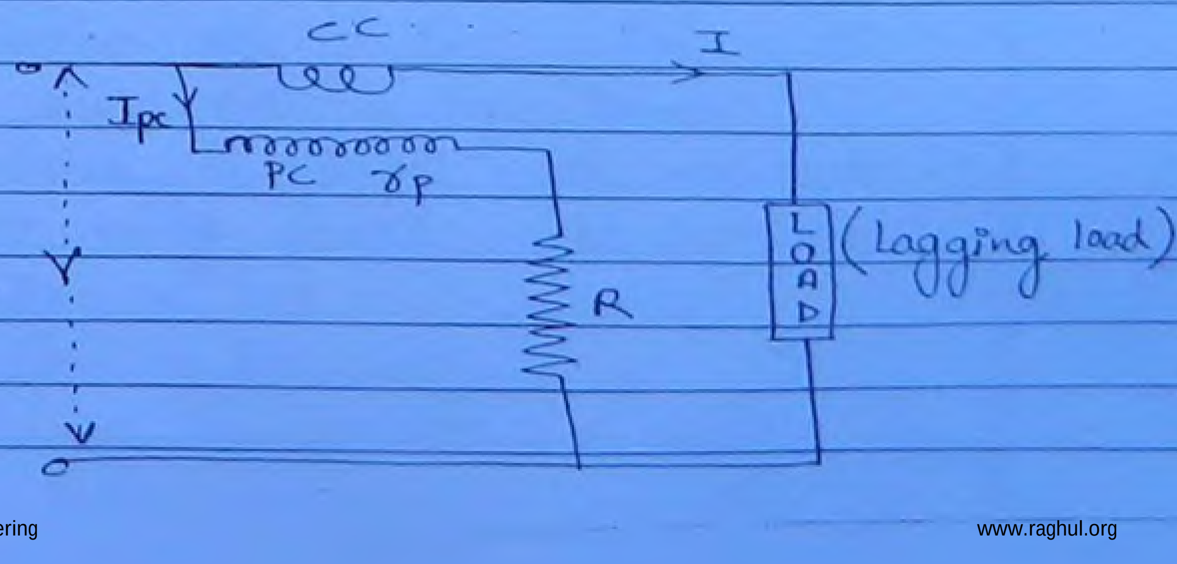
i.e "For low power measurement"

In fig.2 where the voltmeter is connected on the load side the reading of the ammeter would contain the sum of the currents through the voltmeter and the load.

From the above analysis, it can be seen that the calculated power in this case would not only contain the power loss desipated by the load but would also contain a component of the power loss in Voltmeter ckt.

As the power loss in the Voltmeter circuit is small and negligible due to its high resistance this ckt could be specially suitable for the measurement of large loads, were a small power loss due to the voltmeter ckt would become negligible.

Measurement of power in a.c circuit



-1. As the expression for the power in the a.c circuit is given as the product of the Current, the voltage and the power factor a normal Ammeter - Voltmeter combination would be unsuitable for the measurement of power in an A.C circuit.

-2. An Electrodynamo meter type of instrument is modified to measure power in an a.c circuit as follows.

(i) The schematic of an electrodynamo meter type of Watt-meter is shown in the fig. above.

(ii) The fixed coil of the instrument which is would with the thick Multi standard wire is connected along the load.

(iii) The fixed coil now known as Current coil carries a current that is being drawn by the load.

The moving coil of the instrument which is wound with a thin wire for a large number of turns is connected either across the supply of or the load.

(v) This coil now known as the pressure coil (PC) is connected either carries the current that is proportional to the voltage.

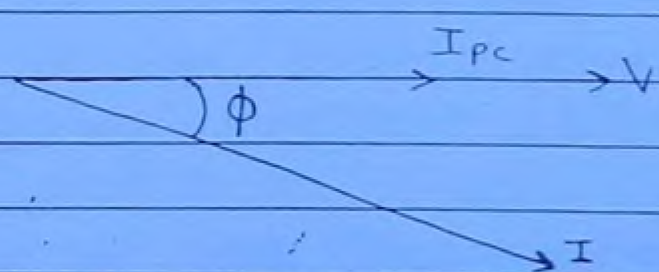
71

(vi) A high resistance R is connected in series with the pressure coil circuit in order to limit the current passing through it to a small value.

Analysis:

As there is a high resistance connected in series with the P.C ckt. The PC is assumed to be purely resistive.

Phasor Relationship:



From the Expression for the Td of an electro dynamo meter type instrument for sinusoidal current we have,

$$T_d = I_1 I_2 \cos \angle_{I_1}^{I_2} \frac{dM}{d\theta}$$

Where,

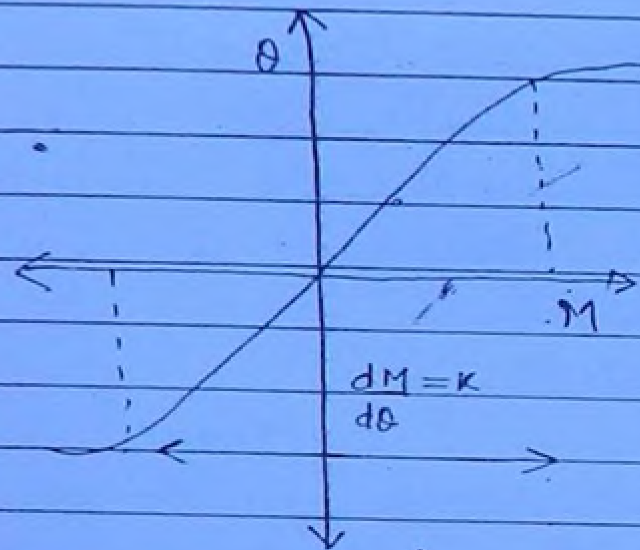
$$I_1 = I_{FC} = I_{CC} = I$$
$$I_2 = I_{MC} = I_{PC} = \frac{V}{R_P}$$

PAGE :
DATE : / /

Where, $R_p = r_p + R$

$\angle(I_1, I_2) = \angle(I_{cc}, I_{pc}) = \phi$ 72

$$\boxed{\therefore T_d = \frac{VI \cos\phi}{R_p} \frac{dM}{d\theta}}$$



As R_p is constant and $\frac{dM}{d\theta}$ is made constant

$$\boxed{\begin{array}{l} T_d = K V I \cos\phi \\ T_d \propto V I \cos\phi \end{array}}$$ or

At steady state position,

$$\boxed{\theta \propto V I \cos\phi}$$

Note: Imp OBJ The electrodynamometer type of wattmeter have the uniform scale and it measures the average value of the active power in the ckt.

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Errors in Electrodynamometer Type of wattmeters:

Interview

IES/CONV – 1. Error due to the pressure coil inductance (23)

– 2. Error due to the pressure coil Capacitance.

IES – 3. Error due to the connections of the pressure Coil

– 4. Error due to Eddy Currents.

– 5. Error due to Stray magnetic fields

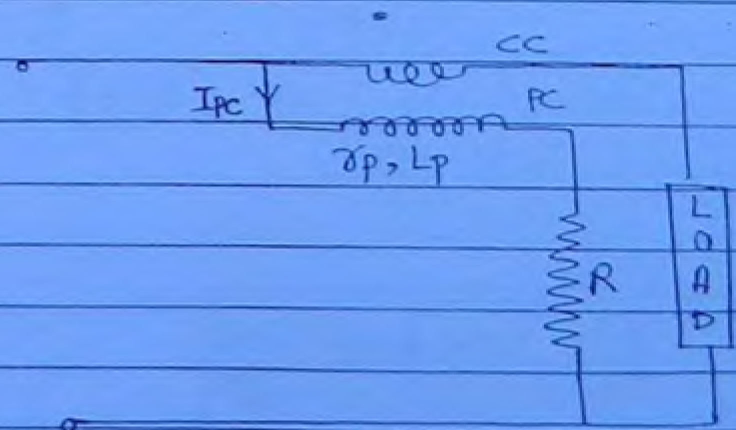
– 6. Error due to the vibration of moving system

1.

(A) **Error due to the pressure coil Inductance:**

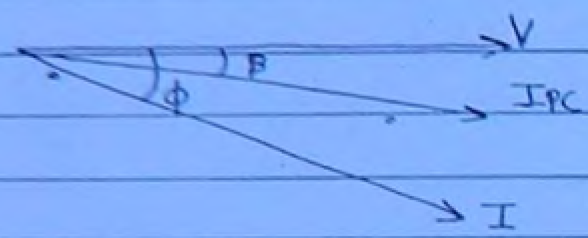
a) Effect of the pressure Coil Inductance on the reading of the Wattmeter.

During the analysis of the working of a Wattmeter it was assumed that the pressure coil was purely resistive, But in practical Wattmeters the pressure coil has a finite inductance and this effect of this pressure coil inductance for both lagging as well as leading loads is discussed below.



Case 1: For lagging Loads:

Drawing the phasor relationship by taking the finite inductance of P.C into consideration we have,



From the Td expression for Sinusoidal Currents of an electrodynamometer instrument we have,

$$T_d = I_1 I_2 \cos \widehat{I_1 I_2} \frac{dM}{d\theta}$$

Where,

$$I_1 = I_{cc} = I$$

$$I_2 = I_{pc} = \frac{V}{Z_p}$$

$$Z_p = R_p + j\omega L_p \qquad (R_p = r + R)$$

$$\therefore \quad Z_p = \sqrt{R_p^2 + (\omega L_p)^2}$$

$$\beta = \tan^{-1}\left(\frac{\omega L_p}{R_p}\right)$$

$$\widehat{I_1 I_2} = \widehat{I_{cc} I_{pc}} = (\phi - \beta)$$

$$\boxed{T_d = \frac{VI}{Z_p} \cos(\phi - \beta) \frac{dM}{d\theta}}$$

Where,

$$\cos\beta = \frac{R_p}{Z_p} \quad (25)$$

$$\boxed{\therefore T_d = \frac{VI}{R_p}\cos\beta\,\cos(\phi-\beta)\,\frac{dM}{d\theta}}$$

As β is small $\cos\beta \cong 1$

$$\boxed{T_d = \frac{VI}{R_p}\cos(\phi-\beta)\,\frac{dM}{d\theta}}$$

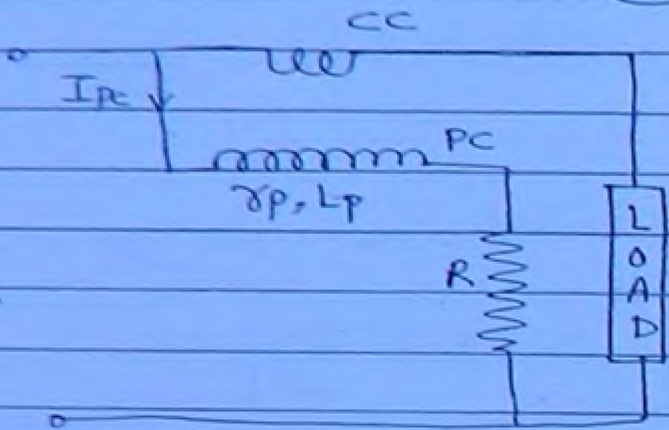
or At SSP,

$$\boxed{\theta \propto VI\cos(\phi-\beta)}$$

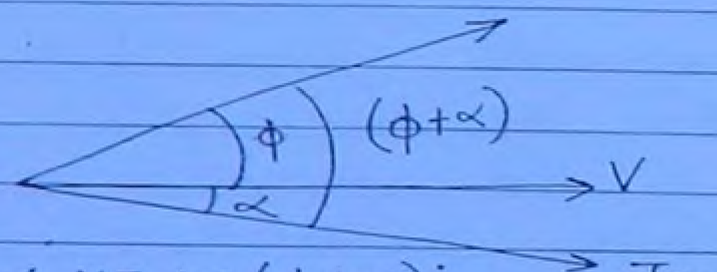
As the apparent power factor angle $(\phi-\beta)$ is less than the true power factor angle ϕ, resulting in the apparent power factor $\cos(\phi-\beta)$ being greater than the actual power factor $\cos\phi$. The Wattmeter reading would be greater than, the true power consumed by the load, due to the effect of the pressure coil inductance on lagging loads.

Case 2: For leading loads

(26)



Drawing the phasor relationships by taking the finite inductance of PC into consideration we have,



$\therefore \theta \propto VI\cos(\phi+\alpha)$.

Note: As the apparent power factor angle $(\phi+\alpha)$ is greater than the actual power factor angle ϕ, resulting in the apparent power factor $\cos(\phi+\alpha)$ being less than the actual power factor angle $\cos\phi$, the wattmeter reading would be lower than the actual power consumed by the load due to the effect of pressure coil inductance on leading loads.

Summary of the effect of pressure coil Inductance:

Lagging Load	Leading Load
1. $(\phi-\beta) < \phi$	1. $(\phi+\alpha) > \phi$
2. $\cos(\phi-\beta) > \cos\phi$	2. $\cos(\phi+\alpha) < \cos\phi$
3. $VI\cos(\phi-\beta) > VI\cos\phi$	3. $VI\cos(\phi+\alpha) < VI\cos\phi$
4. Wattmeter Reading > True power	4. Wattmeter Reading < True power

77

3) Expression for the Correction factor:

$$\text{Correction factor} = \frac{\text{True power}}{\text{Measured power}}$$

$$C.F = \frac{\cancel{VI}\cos\phi}{\cancel{VI}\cos\beta\cos(\phi-\beta)}$$

$$= \frac{\cos\phi}{\cos\beta\cdot\cos(\phi-\beta)}$$

$$= \frac{\cos\phi}{\cos\beta\cdot[\cos\phi\cos\beta + \sin\phi\sin\beta]}$$

$$= \frac{\cos\phi}{\cos^2\beta[\cos\phi + \sin\phi\tan\beta]}$$

DATE : / /

As β is small,

$\cos^2\beta \simeq 1$

$$C.F = \frac{\cos\phi}{\cos\phi + \sin\phi \tan\beta} \quad (78)$$

$$= \frac{\cos\phi}{\cos\phi\left[1 + \tan\phi \tan\beta\right]}$$

$$\therefore C.F = \frac{1}{1 + \tan\phi \tan\beta}$$

Now,

$$\frac{\text{True power}}{\text{Measured power}} = \frac{1}{1 + \tan\phi \tan\beta}$$

or, Measured power = True power + $\tan\phi \tan\beta$ * true power

Measured power − True power = $\tan\phi \tan\beta$ * true power

$\therefore$ Error = $\tan\phi \tan\beta$ * true power

$$\therefore \text{Percentage Error} = \frac{\text{Measured Value} - \text{True Value}}{\text{True value}} \times 100$$

$$= \frac{\tan\phi \tan\beta * \cancel{\text{True power}}}{\cancel{\text{True power}}} \times 100$$

$$\boxed{\%\ \text{Error} = \tan\phi \ \tan\beta \times 100}$$

29

Q1. The Voltage ckt. of an electrodynamic Wattmeter has an inductance of 8 mH and a resistance of 2000 Ω. What is the % of error of the instrument when measuring an inductance load having a phase angle of 89° at 50 Hz. Neglect the impedance of the Current Coil and assume the potential ckt Current is negligible as compared with the load Current.

Soln:
$$\beta = \tan^{-1}\left(\frac{\omega L_P}{R_P}\right)$$
$$= \tan^{-1}\left(\frac{2\pi \times 50 \times 8 \times 10^{-3}}{2000}\right)$$
$$\tan\beta = 1.25 \times 10^{-3}$$
$$\tan\phi = \cancel{89^\circ}\ 57.28$$
$$\therefore \text{Error} = \tan\phi \cdot \tan\beta \times 100$$
$$= 1.25 \times 10^{-3} \times 57.28 \times 100$$
$$\%\ \text{Error} = 7.19\ \%$$

(c) **Compensation for the error due to pressure Coil Inductance:**

(80)

→ The error due to the pressure coil inductance becomes evident while Calculating the pressure coil Current I_{pc}.

Where,

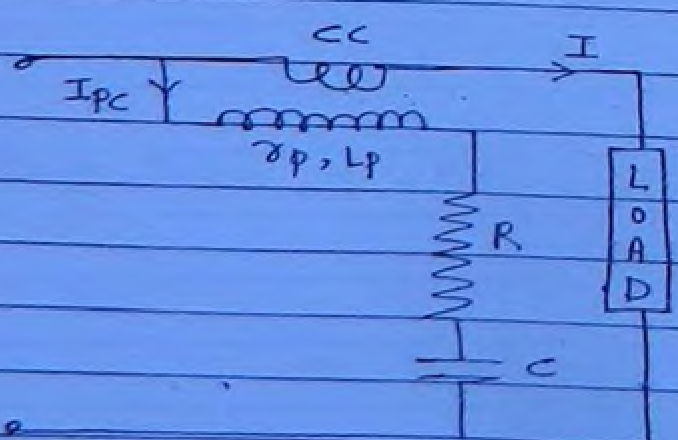
$$\boxed{I_{PC} = \frac{V}{Z_P}}$$

→ If Z_p is made equal to R_p then the effect of the pressure coil inductance is negated and I_{pc} can be expressed as,

$$\boxed{I_{PC} = \frac{V}{R_P}}$$

→ This can be done by introducing a capacitive reactance in the ckt. in order to compensate for the effect of the inductive reactance.

1. **Capacitance in Series with P.C**



Calculating the impedance of the P.C ckt we have

$$Z_p = R + r_p + j\omega L_p + \frac{1}{j\omega C} \quad (81)$$

as $R_p = R + r_p$ we have,

$$Z_p = R_p + j\omega L_p - \frac{j}{\omega C}$$

$$\boxed{Z_p = R_p + j\left(\omega L_p - \frac{1}{\omega C}\right)}$$

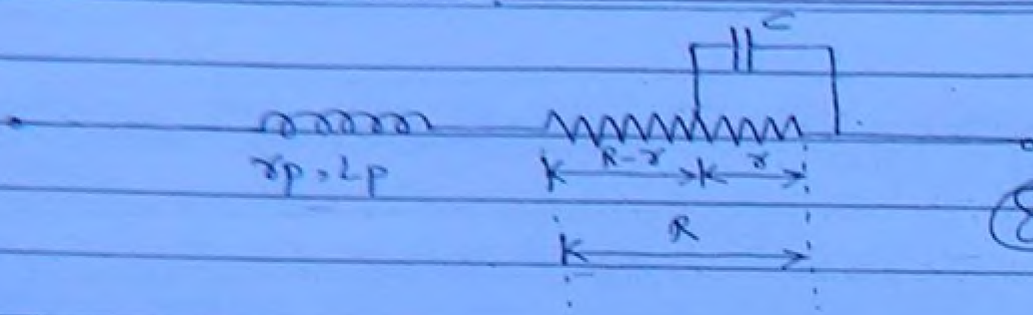
If value of C is so choosen that the term $\left(\omega L_p - \frac{1}{\omega C}\right) = 0$

then, $\boxed{Z_p = R_p}$

As the expression, $\omega L_p - \frac{1}{\omega C} = 0$, it satisfied at only one value of 'ω'.

This methodology for Compensating the error due to pressure coil inductance is never used.

Capacitance across Certain sections of the high resistance Connected in Series with the pressure Coil Circuit:



Calculate the value of the P.C impedance we have,

$$Z_p = r_p + j\omega L_p + R - r + \left(r \parallel \frac{1}{j\omega C}\right)$$

As, $R_p = r_p + R$

$$Z_p = R_p + j\omega L_p - r + \frac{r}{j\omega C\left(r + \frac{1}{j\omega C}\right)}$$

$$Z_p = R_p + j\omega L_p - r + \frac{r}{r j\omega C + 1}$$

Multiplying and dividing by $\frac{r}{(1 + j\omega C r)}$ by $(1 - j\omega C r)$ we have,

$$Z_p = R_p + j\omega L_p - r + \frac{r(1 - j\omega C r)}{(1 + j\omega C r)(1 - j\omega C r)}$$

$$Z_p = R_p + j\omega L_p - r + \frac{r(1 - j\omega C r)}{1 + \omega^2 C^2 r^2}$$

if r is choosen to be very small then, $1 + \omega^2 C^2 r^2 \cong 1$.

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$$\therefore Z_p = R_p + j\omega L_p - r + r - j\omega C r^2$$

$$\boxed{Z_p = R_p + j\omega\left(L_p - C r^2\right)} \quad (83)$$

If the value of C is so choosen that

$$\boxed{L_p - C r^2 = 0}$$

then,

$$Z_p = R_p.$$

Note: The above Compensation methodology yields an expression that is independent of frequency and hence, can be used at all frequencies.

The above methodology fails under the following conditions:

- (i) If the freqn is greater than 10 KHz.
- (ii) If the value of 'r' becomes large then, the expression "$1 + \omega^2 C^2 r^2$" will no longer be equal to '1' and the entire analysis for Compensation fails.

Error due to pressure Coil Capacitance :

84

-1. The error due to the pressure coil capacitance is because of the 'intra turn' or the distributed capacitance of the pressure coil ckt.

-2. The effect of the pressure coil capacitance would be exactly opposite to that of the effect of the pressure coil 'inductance'.

i.e " At lagging loads, the wattmeter would give lower reading and at leading loads the wattmeter would end-up giving a higher reading.

-3. If the inductance and the capacitive reactance of the pressure coil ckt are made equal then the effect of both the error due to pressure coil inductance and the error due to pressure coil capacitance are compensated.

3. Error due to pressure coil Connection :

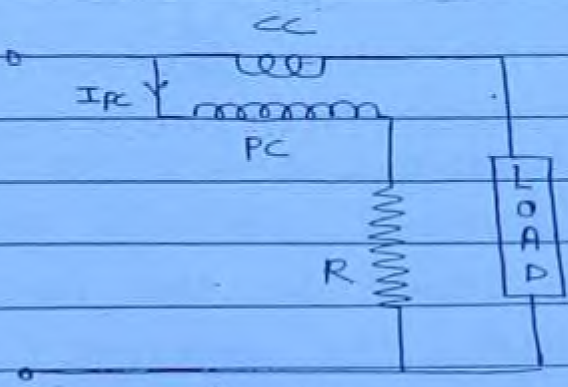


fig (1)

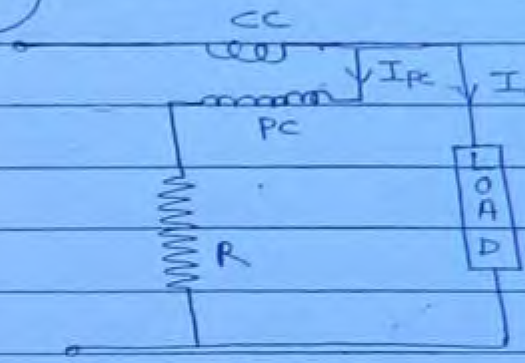


fig (2)

-1. The above two figures show the possible connection methodology of the pressure coil ckt in an electrodyndmometer type Wattmeter.

-2. In fig(1). where the current coil is connected on the load side the pressure coil current Ipc would be a function of the sum of the voltage drop across the current coil and the load.

Thus, in this Connection methodalogy the reading of the Wattmeter would be the sum of the power dissipated by the load and the power loss in the current coil ckt.

Wattmeter Reading = Load power + power loss in C.C

$$\boxed{\text{Wattmeter Reading} = VI\cos\phi + I^2R}$$

-3. As the power loss in the C.C varies as the square of the load current, this connection methodology would be suitable for load that

draw less current or for low power measurement.

86

-4. In fig (2). Where the pressure coil is on the load side, the Current through the current coil circuit would be the sum of the Currents through the pressure coil and the load.

-5. Thus the Wattmeter reading in this Connection methodology would not only contain a component of the power dissipated by the load but would also contain a component of the power loss in the PC circuit.

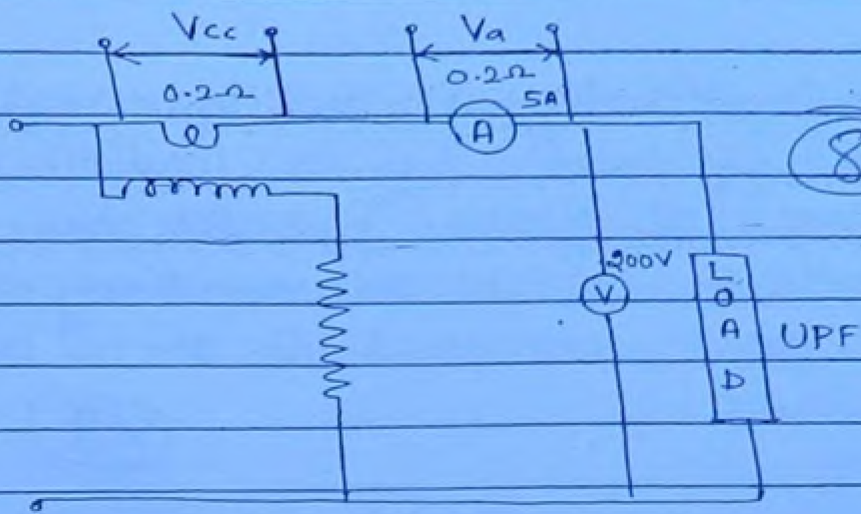
Wattmeter Reading = Load power + power loss in PC

$$\boxed{= VI\cos\phi + V^2/R}$$

-6. As the power loss in the P.C ckt. is small this Connection methodology would be suitable for the measurement of high power measurement which would make the small value of the power loss in the P.C ckt negligible.

ote: Electrodynamometer type of wattmeter are generally Compensated for the power loss in the p.c ckt.

Q1.



87

Soln : $P = VI$

$= (5 \times 0.2 + 5 \times 0.2 + 200)\, 5$

$P = 1010\, W$

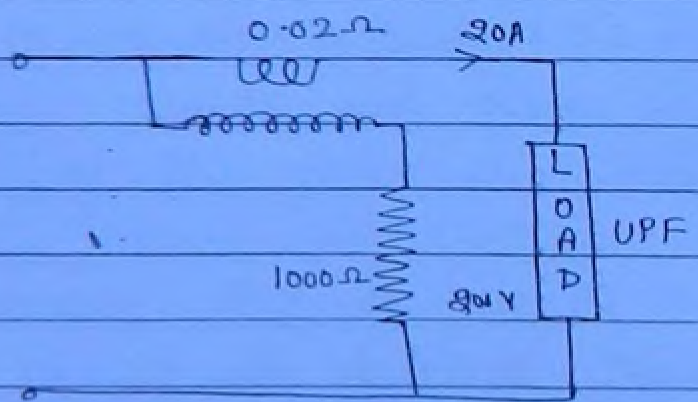
Q2 The Current through the CC of the wattmeter is given by $I_{cc} = 1 + 2\sin\omega t$ A and the voltage across the pressure coil is $V_{PC} = 2 + 3\sin(2\omega t)$ V. The wattmeter will read

a) 8 W   b) 5 W   c) 2 W   d) 1 W

Soln: Note: The frequency of the signal supplied to the pressure coil and the current coil are different. Hence, the wattmeter will read only the d.c component of the power.

Q3. The ckt. in the fig. is used to measure the power consumed by the load. The CC and voltage coil of the Wattmeter have $0.02\,\Omega$ and $1000\,\Omega$ resistances respectively. The measured power compared to the load power will be 88

a) 0.4 % less b) 0.2 % less c) 0.2 % more d) 0.4 % more



Soln: Measured power $= VI\cos\phi + I^2R$

$= 20 \times 200 \times 1 + (20)^2(0.02)$

$= 4008$

True power $= 4000$

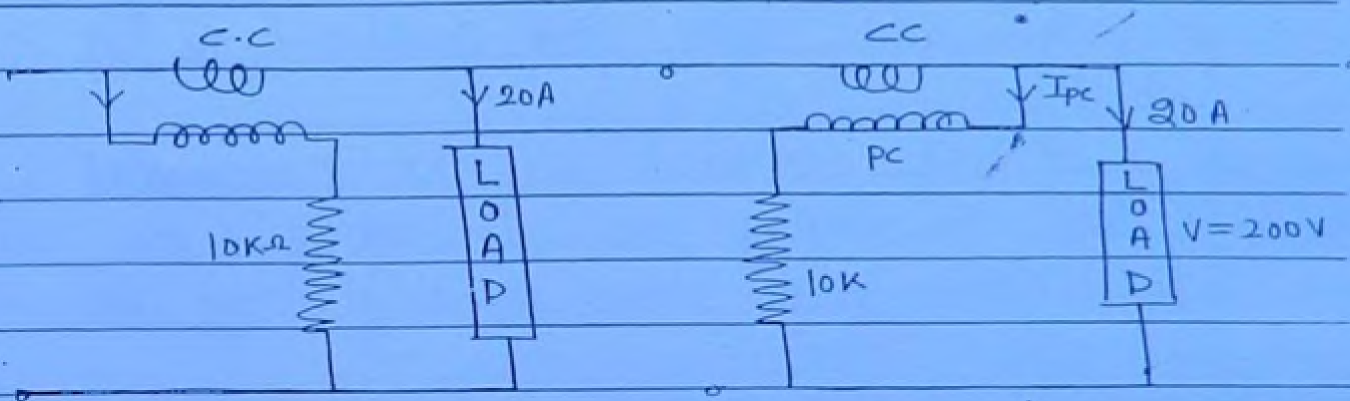
% Error $= \dfrac{4008 - 4000}{4000} \times 100$

$= +0.2\,\%$

$= 0.2\,\%$ more.

4 2 types of the Connection of Wattmeter pressure coil are shown in the fig. The value of the wattmeter Current coil resistance 'r' which will make the Connection errors the same in 2 cases is,

89



Soln: To make the error equal means,

$$I^2 r = \frac{V^2}{R}$$

$$20 \times 20 \times r = \frac{200 \times 200}{R}$$

$$\therefore r = \frac{200 \times 200}{20 \times 20 \times 10 \times 10^3}$$

$$r = 100 \times 10^{-4}$$

$$\therefore r = 0.01\Omega$$

4. Errors due to Eddy Currents: 90

Errors due to eddy currents in an electrodynamometer wattmeter occur due to the eddy currents induced by the interaction of the alternating flux of the current coil with the conductors in its vicinity.

These errors can be compensated by either insulating or eliminating the conductors from the vicinity of the current coil.

5. Errors due to Stray magnetic fields:

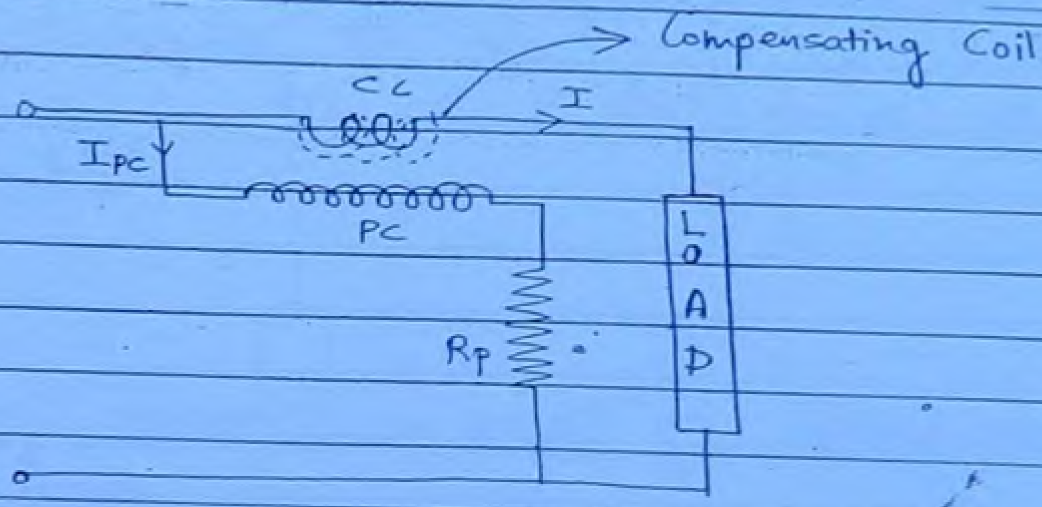
These Errors can be compensated by providing proper magnetic shielding in the instrument.

6. Errors due to the vibrations of the moving system:

These errors can be eliminated by placing the wattmeter on a thick sheet of rubber while taking down the measurement.

Low power Factor Wattmeter:

(91)



- As $\phi \rightarrow 90^\circ$, $\cos\phi \rightarrow 0$ and the deflecting torque in an electrodynamometer type wattmeter tends to 'zero' thereby making it unsuitable for the measurement of power in low power factor ckt.

- In order to make it suitable for the measurement of power in a LPF ckt. the following modifications are made in an electrodynamometer type wattmeter.

— (i) The angle of deflection of the instrument is increased by incorporating a weaker control mechanism.

— (ii) The deflecting torque of the instrument is increased by decreasing the resistance in the pressure coil ckt. which results in an increased pressure coil current.

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(iii) The Compensating coil is wound on a C.C ckt. in order to compensate for the power loss in P.C ckt.

(92)

→ Measurement of Power in Polyphase Circuit

Power in polyphase ckt. is measured by single phase electrodynamometer type watt-meters on the basis of the "Blonde's Theorem".

The Blondle's theorem states,

1. In an N phase N+1 wire system, N wattmeters are required for the measurement of power where, the Current coil of these N wattmeters are connected in the respective phases and their p.c are connected between that phase and the phase designated as the common phase.

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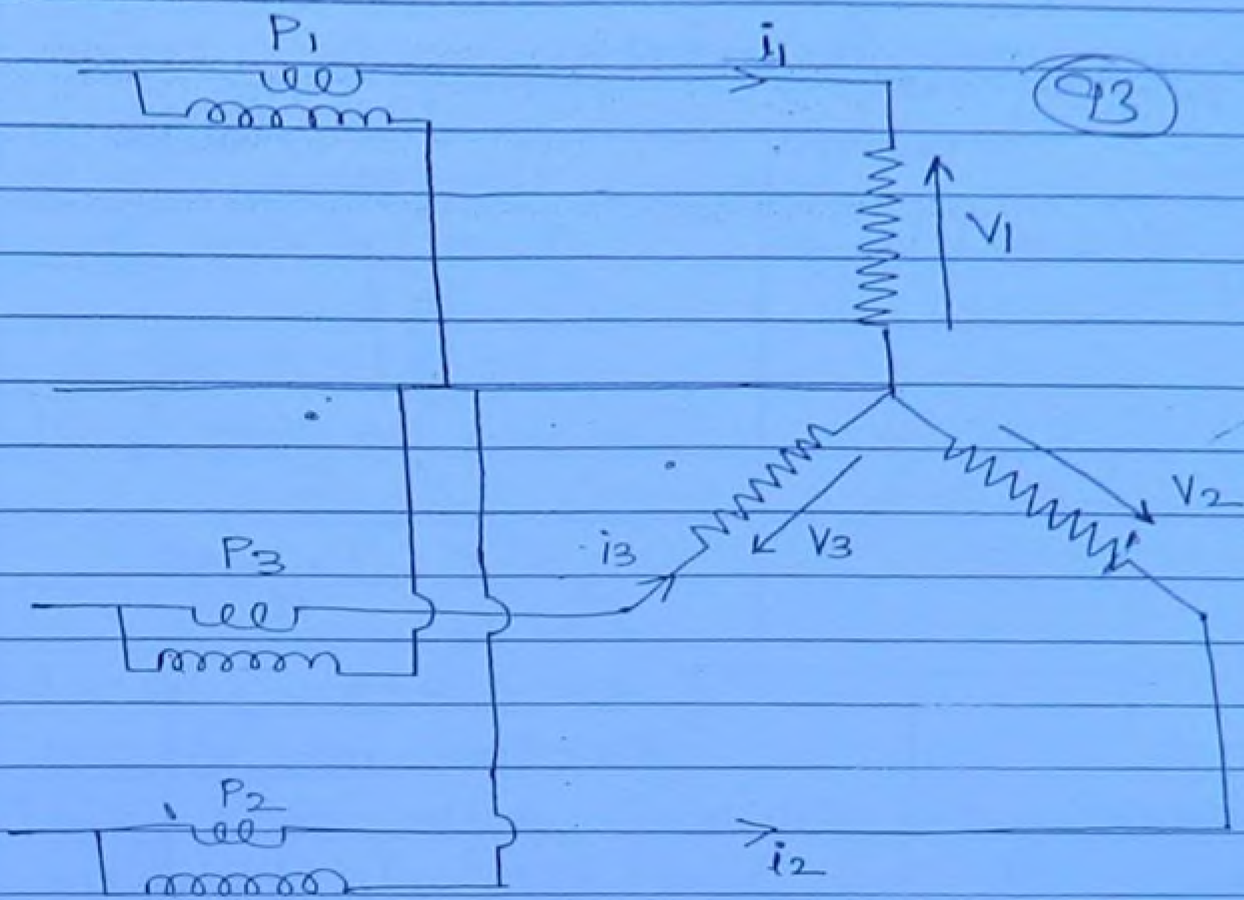
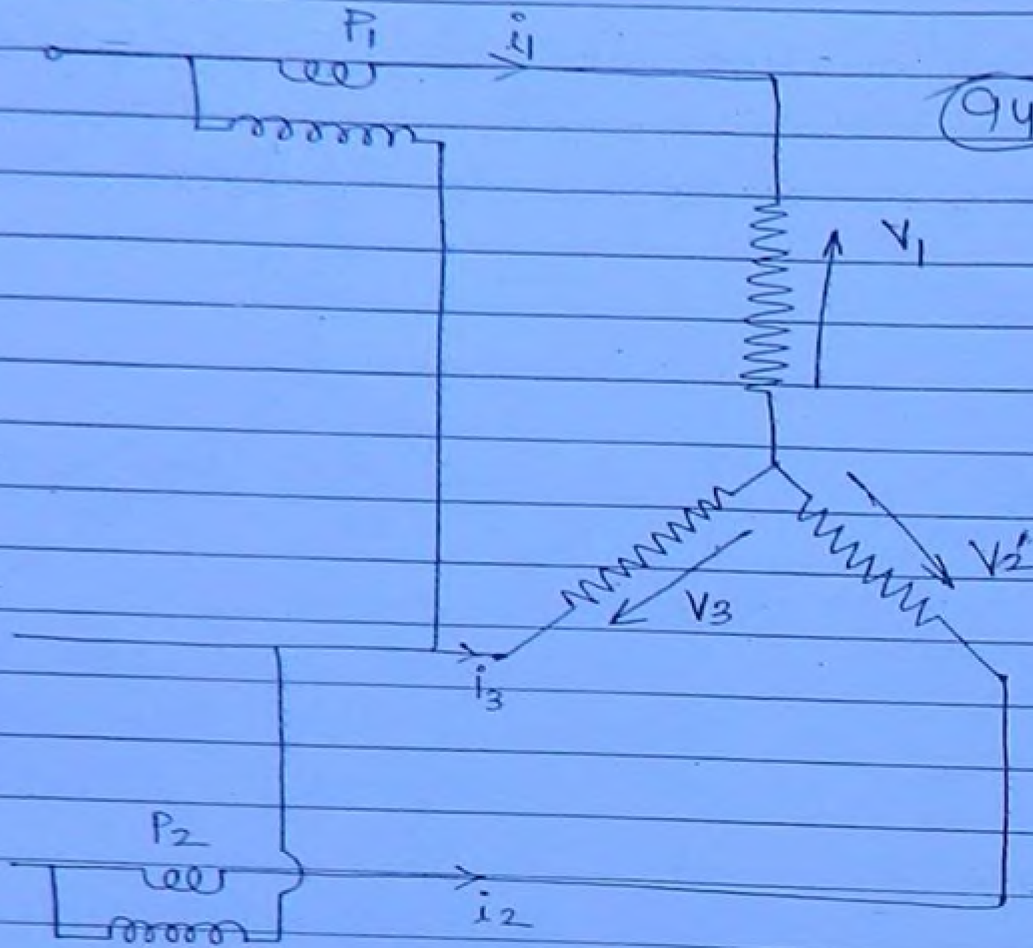


$$P = P_1 + P_2 + P_3$$
$$= i_1V_1 + i_2V_2 + i_3V_3$$

2. In an N phase, N wire system; N-1 Wattmeters are required for the measurement of power, where the Current coils of the N-1 wattmeter are connected in the N-1 phases and their pressure coils are connected between that phase and the phase designated as the common phase.



$$P = P_1 + P_2$$

$$= i_1(V_1 - V_3) + i_2(V_2 - V_3)$$

$$= i_1V_1 - i_1V_3 + i_2V_2 - i_2V_3$$

$$= i_1V_1 + i_2V_2 - V_3(i_1 + i_2)$$

From KCL we have

$$i_1 + i_2 + i_3 = 0$$

or $\quad i_3 = -(i_1 + i_2)$

$$\boxed{\therefore \quad P = V_1 i_1 + V_2 i_2 + V_3 i_3}$$

Imp (P.S.U)

Effect of power factor on reading of Wattmeter

95

-1. $\phi = 0$, $\cos\phi = 1$.

P_1 will be $= \frac{P}{2}$, P_2 will be $= \frac{P}{2}$

$\therefore \cancel{P} = P_1 + P_2 = P$

$= \frac{P}{2} + \frac{P}{2}$

$= P$

-2. $\phi = 60$, $\cos\phi = 0.5$

one of the wattmeter indicates a 'zero', While the other indicates the total power consumed by the load.

-3. $\phi = 90^\circ$, $\cos\phi = 0$

Then,

$P_1 = \frac{P}{2}$, and $P_2 = \frac{P}{2}$

But one of the wattmeter gives a -ve reading.

Note: → If the reading of both the Wattmeters are +ve then the power factor angle is between 0 and 60°.

→ If one of the wattmeter reads a -ve value and the other reads a +ve value the phase angle of the load is between 60 and 90°.

In instances where the phase angle is between 60 and 90° the current coil connections of the wattmeter that shows the -ve reading are reversed before the readings are noted down.

96

The value of the phase angle ϕ can be calculated from the readings of the two wattmeters as,

$$\boxed{\phi = \tan^{-1}\left\{\frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}\right\}}$$

Q1. The power of a 3ϕ, 3 wire balanced system was measured by the 2 wattmeter method. The readings of one of the wattmeter was found to be double of the other. What is the power factor of the system.

Sln:

$$\phi = \tan^{-1}\left\{\frac{\sqrt{3}(P_1 - P_2)}{(P_1 + P_2)}\right\}$$

$$P_1 = 2P_2$$

$$\phi = \tan^{-1}\left\{\frac{\sqrt{3}(2P - P)}{3P}\right\}$$

$$= \tan^{-1}\left\{\frac{1}{\sqrt{3}}\right\}$$

$$\therefore \cos\phi = \frac{\sqrt{3}}{2}.$$

Q2. 2 Wattmeters which are connected to measure the total power on a 3-ϕ system Supplying a balanced load read 10.5 KW and − 2.5 KW resp. The total power & power factor resp. are (97)

a) 13 KW & 0.334
b) 13 KW & 0.684
c) 8 KW & 0.52
d) 8 KW & 0.334

Soln:

Q3. In the measurement of power by balanced load by a 2 Wattmeter method in a 3-ϕ ckt. the readings of the wattmeter are, 3 KW & 1 KW resp. The latter being obtained after reversing the Connections to the Current coil. The power factor of the load is

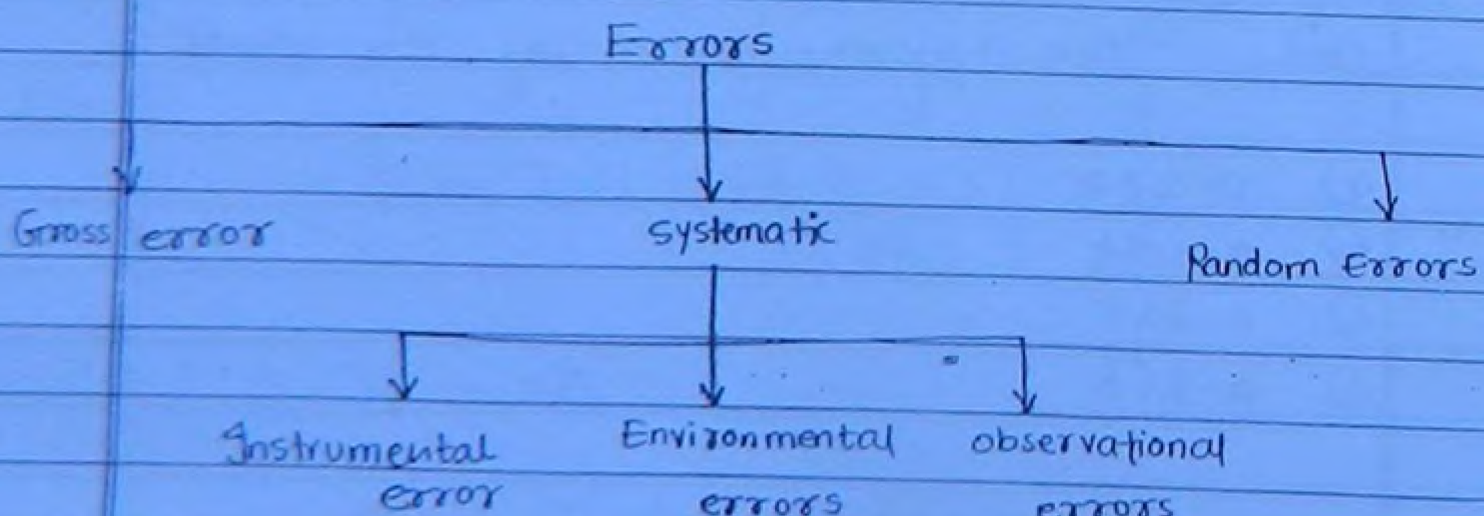
a) 0.277
b) 0.554
c) 0.625
d) 0.866

V. Imp PSU — Classification of Error's. (C/8)
ES/PSU ** — Limiting Error Analysis.
ES/conv — Limiting Error in Combination of Quantities.
ES/PSU obj — Uncertainity Analysis.

Classification of Errors

Error can be defined as the deviation of the measured value from the true value.

Errors in the instrument or an measurement system are classified on the basis of the source, the mode of propagation, the probability of Occurance and its Magnitude.



99

Gross errors: are those errors which occur due to the human factors involved in the measurement of a particular parameter

Typical examples of these errors will be -

- (i) Errors due to the carelessness of the user while noting down the reading of instrument
- (ii) Selection of an instrument with an improper range while by an inexperienced user.
- (iii) All Instrument related errors are classified as Systematic Errors.

These errors can be further classified as

- 1. Instrumental errors - Which occur due to the Sub-standard design / Components used while fabricating the instrument.

Example:

- (i) Errors due to improper temperature Compensation in Ammeters and Voltmeters
- (ii) Using shunts and Multipliers made up of materials which have a higher temperature Co-efficients.

2. Environmental Errors – These errors occur due to external Conditions such as temperature, Stray electrostatic or electromagnetic fields, humidity etc. (100)

3. observational Errors – They are those errors which occur due to improper observational methodologies incorporated in the instrument

Typical example of this error is error due to "Paralax".

Random Errors

These are those errors which occur due when the source, the mode of propagation, probability of Occurance and the magnitude of a particular error cannot be ascertained.

The net magnitude of the random errors in the measurement system is negligible as the cause of one would generally Compensate for the effect of other

If the deviation of the measured value from the true value is specified by the manufacturer himsef, then this error

is known as the "limiting error" or "Gaurantee error".

$$\boxed{A_a = A_s \pm \delta A} \quad (101) \quad \text{—— (1)}$$

Where,

A_a = Actual value / measured value.

A_s = Nominal value / True value.

δA = Absolute limiting error. (ϵ_0).

As the absolute value of the limiting error does not signify any meaning it is always specified in terms of its true value (ϵ_r).

$$\boxed{\therefore \text{ Relative limiting error} = \frac{\delta A}{A_s}} \quad \text{—— (2)}$$

$$\boxed{\% \ \epsilon_r = \frac{\delta A}{A_s} \times 100} \quad \text{—— (3)}$$

from eq - (2) we have,

$$\boxed{\delta A = A_s \epsilon_r}$$

Substituting the above expression in eq - (1). we have,

$$\boxed{A_a = A_s (1 \pm \epsilon_r)} \quad \text{—— (4)}$$

The value of $\pm \delta A$ from exp (1) can be written as

$$\boxed{\pm \delta A = A_a - A_s}$$

Substituting the above exp. in - (3) we have,

$$\% \epsilon_r = \frac{A_a - A_s}{A_s} \times 100$$

(102)

$$\boxed{\% \epsilon_r = \frac{\text{Measured Value} - \text{True Value}}{\text{True Value}} \times 100}$$

Q1. A 0-300V Voltmeter has a Gauranteed accuracy of 2% of the full scale reading. If the voltage being measured by the instrument is 180 V. Then the limiting error will be,

a) less than 2%
b) greater than 3% but less than 2%
c) less than 4% but greater than 3%
d) 4%

Ans: 0 - 300V ± 2% FSD

$\therefore \delta A = 2\%$ of 300
$= 6\,V$

$A_s = 180V$

$$\therefore \frac{\delta A}{A_s} \times 100 = \frac{6}{180} \times 100 = 3.33\%$$

2) A Wattmeter has a range of 1000 W with an error 1% of FSD. If the true power passed through it is 100W then

DATE: / /

the relative error will be

a) ±10% b) ±5% c) ±1% d) ±0.5%

Soln: 8

103

Q3 As the pointer of the indicating instrument moves away from the zero position its absolute limiting error

a) Increases with increase in deflection
b) decreases with increase in deflection
c) remains constant all over the range
d) Can't be ascertained

Q4. As the pointer of the indicating instrument moves away from the zero position its relative limiting error,

a) Increases with increase in deflection.
b) decreases with increase in deflection.
c) Remains constant
d) Can't be ascertained.

Note: As the pointer of an indicating instrument moves away from the zero position its relative limiting error decreases with increase in deflection and its absolute limiting error remains constant throughout the scale.

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Imp

Loading effect

1. CRO (Min)
2. digital instrument
3. electronic instrument
4. electrical instrument (Max)

104

→ **Limiting errors in Combination of Quantities**

1. Sum or the Difference of two or more than two Parameters.

Let $X = x_1 + x_2 + x_3$

∴ Relative limiting error of X will be,

$$\boxed{\frac{\delta X}{X} = \pm\left\{\frac{x_1}{X}\frac{\delta x_1}{x_1} + \frac{x_2}{X}\cdot\frac{\delta x_2}{x_2} + \frac{x_3}{X}\cdot\frac{\delta x_3}{x_3}\right\}}$$

Q1. A 4 dial decaded resistance box has its terminal specified as,

$x_1 \times 1000 \pm 0.1\%$

$x_2 \times 100 \pm 0.1\%$

$x_3 \times 10 \pm 0.5\%$

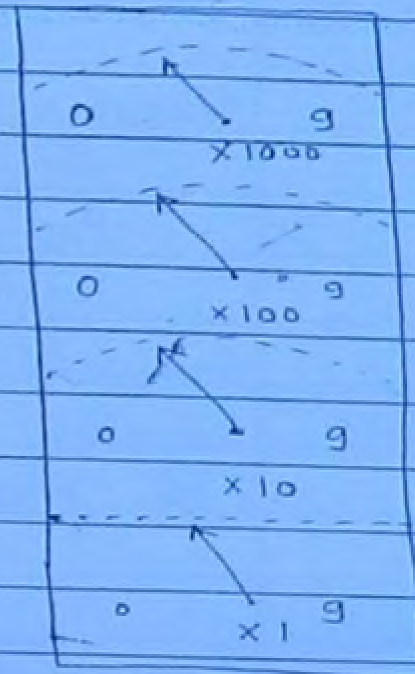
$x_4 \times 1 \pm 1\%$

If the resistance across the terminals of a decade resistance box is $4739\,\Omega$. Calculate the limiting error involved in

its measurement both in Ω and in %.

Soln:

Tas



$$\therefore 4 \times 1000 \pm 0.1\% = 4000 \pm 4.0\,\Omega$$
$$7 \times 100 \pm 0.1\% = 700 \pm 0.7\,\Omega$$
$$3 \times 10 \pm 0.5\% = 30 \pm 0.15\,\Omega$$
$$9 \times 1 \pm 1\% = 9 \pm 0.09\,\Omega$$
$$4739 \pm 4.94\,\Omega$$

$$\therefore \frac{\delta A}{A_s} \times 100$$

$$= \frac{4.94}{4739} \times 100$$

$$= 0.104\%$$

~~product of the Quotient~~

Product of the Quotient of two or more than two parameters:

Let $X = x_1 \cdot x_2 \cdot x_3$

$\therefore$ Relative limiting error of X will be,

$$\boxed{\frac{\delta X}{X} = \pm \left\{ \frac{\delta x_1}{x_1} + \frac{\delta x_2}{x_2} + \frac{\delta x_3}{x_3} \right\}}$$

Q1. The value of an unknown resistance is calculated by using Wheatstone's bridge as $R_4 = \frac{R_2 \cdot R_3}{R_1}$.

Where:

(106)

$R_1 = 100\,\Omega \pm 0.5\%$

$R_2 = 1000\,\Omega \pm 0.5\%$

$R_3 = 842\,\Omega \pm 0.5\%$

Calculate the value of the unknown resistor and the limiting error involved in its measurement in both Ω and in %.

Soln:

$R_1 = 100 \pm 0.5\% = 100 \pm 0.5$

$R_2 = 1000 \pm 0.5\% = 1000 \pm 5$

$R_3 = 842 \pm 0.5\% = 842 \pm 42.1$

$$R_4 = \frac{1000 \times 842}{100}$$

$\therefore R_4 = 8420\,\Omega$

$$\therefore \frac{\delta R_4}{R_4} \times 100 = \pm \left\{ \frac{\delta R_1}{R_1} \times 100 + \frac{\delta R_2}{R_2} \times 100 + \frac{\delta R_3}{R_3} \times 100 \right\}$$

$$= \pm \{ 0.5 + 0.5 + 0.5 \}$$

$$= \pm 1.5\%$$

in %. $\pm 1.5\%$ of $8420 = 8420 \pm 126.3\,\Omega$

3. Power or a factor of two or more than two parameters:

Let $X = x_1^n$ (107)

$$\boxed{\frac{\delta X}{X} = \pm\left\{n \cdot \frac{\delta x_1}{x_1}\right\}}$$

4. Composite factors

Let $X = x_1^n \cdot x_2^m$

$$\boxed{\frac{\delta X}{X} = \pm\left\{n\frac{\delta x_1}{x_1} + m\frac{\delta x_2}{x_2}\right\}}$$

Q1. The limiting errors of measurement of power consumed by and the current passing through a resistance are, $\pm 1.5\%$ and $\pm 1\%$. resp. The limiting error for the measurement of resistance will then be,

Soln: $P = RI^2$

$\therefore R = \frac{P}{I^2}$

$$\frac{\delta R}{R}\times 100 = \pm\left\{1 \cdot \frac{\delta P}{P}\times 100 + 2 \cdot \frac{\delta I}{I}\times 100\right\}$$

$$= \pm\left\{1 \cdot (1.5) + 2(1)\right\}$$

$$= \pm 3.5\%$$

$$\frac{\delta R}{R}\times 100 = \pm\left\{1 \cdot \frac{\delta P}{P}\times 100 + 2 \cdot \frac{\delta I}{I}\times 100\right\}$$

$$= \pm\left\{1 \cdot (1.5) + 2(1)\right\}$$

$$= \pm 3.5\%$$

⇒ Uncertainity Analysis:

108

If the deviation of the measured value from the true value is specified for a uni or a single sample of data either interms of the degree of confidence of the user or the odd's against which the measurement was taken. Then this deviation is known as the Uncertainity involved in the measurement of that parameter.

It is important to note that the uncertainity involved in the measurement of certain parameter is always specified for a single sample of the measurement.

Mathematically expressed,

Uncertainity in the measurement of a parameter that is function of a single variable can be written as,

$$\boxed{X = \overline{X} \pm \omega_x} \quad (n).$$

where,

X = Measured value

$\overline{X}$ = True value

ω_x = Absolute Uncertainity.

n = number of odds / degree of confidence of the user under which the measurement was taken.

(09)

Let X be a function of several variables.

Where,

$$X = f(x_1, x_2, x_3 \ldots\ldots, x_n).$$

if $w_{x_1}, w_{x_2}, w_{x_3} \ldots w_{x_n}$ are the absolute uncertainities involved in the measurement of $x_1, x_2, x_3 \ldots\ldots x_n$ under the same degree of odds then the absolute uncertainity involved in the measurement of X will be

Imp (P.S.U)

$$\boxed{w_X = \pm\sqrt{\left(\frac{\partial X}{\partial x_1}\right)^2 w_{x_1}^2 + \left(\frac{\partial X}{\partial x_2}\right)^2 w_{x_2}^2 + \cdots \left(\frac{\partial X}{\partial x_n}\right)^2 w_{x_n}^2}}$$

The relative uncertainity can be expressed as,

(I.E.S)

$$\boxed{\frac{w_X}{X} = \pm\sqrt{\left(\frac{w_{x_1}}{x_1}\right)^2 + \left(\frac{w_{x_2}}{x_2}\right)^2 + \cdots\cdots + \left(\frac{w_{x_n}}{x_n}\right)^2}}$$

Q1. Power in a d.c ckt. is calculated as the product of the current and voltage if the values of the current and the voltage are given by 6.3 A and 110.2 V and the uncertainities involved in their measurement being 0.06 A and 0.1 V. Calculate the power

dissipated by the load and the uncertainity involved in its measurement.

Soln:

$$P = VI \quad \text{(given)}.$$

110.

$$= 110.2 \times 6.3$$

$$= 694.26 \text{ watts}$$

$$w_p = \pm\sqrt{\left(\frac{\partial P}{\partial V}\right)^2 w_V^2 + \left(\frac{\partial P}{\partial I}\right)^2 w_I^2}$$

Now,

$$\frac{\partial P}{\partial V} = \frac{\partial (VI)}{\partial V} = I = 6.3$$

$$\frac{\partial P}{\partial I} = \frac{\partial (VI)}{\partial I} = V = 110.2$$

$$\therefore w_p = \pm\sqrt{(6.3)^2 \times (0.1)^2 + (110.2)^2 \times (0.06)^2}$$

$$\therefore w_p = \pm 6.64 \text{ watts}$$

: TRANSDUCERS :

(1.1)

Transducer is a device that converts one form of energy to the other.
Generally, from a non-electrical form to an electrical form.

Transducers are basically classified as,
1. Primary Transducers and
2. Secondary Transducers.

<u>Primary transducers</u> – These are those devices which actually sense the paramater under measurement. These are generally mechanical transducers that convert the sensed parameter into an proportional mechanical signal.

<u>Secondary transducers</u> – These are those devices which sense the o/p of the primary transducer and converts it into an analogous electrical signal.

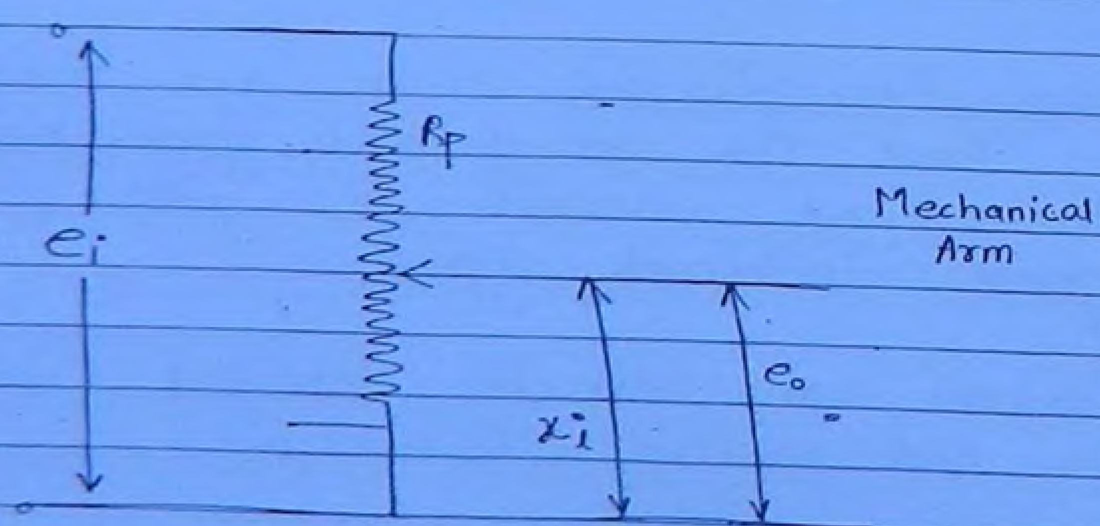
Transducers can also be classified as active and passive transducers.

<u>Active Transducers</u> – Also known as "self generating transducers are those devices which do not require any external source of stimulus for their operation.

Example : Thermo couples
Photo voltaic cells
piezo electric crystals } Imp. (TT2)

Passive transducers – They are those devices which require an external source of stimulii for indicating their o/p.

Examples : Variable R,
Variable C,
and Variable L transducers } Imp.



→ The above schematic shows a linear potentiometer which bases its operation on the change in resistance due to displacement.

2. These Transducers can be used for the measurement of both linear as well as angular displacement. (113)

3. It basically consist of a resistive element R_p of length x_p on which a mechanical arm is placed.

4. The displacement under measurement (x_i) is applied to the mechanical arm due to which the arm gets displaced over the resistive element.

R_p = Total resistance of the resistive element
x_t = length of the resistive element
$\frac{R_p}{x_t}$ = Resistance / unit length

If the displacement applied to the mechanical arm displaces it over R_p by x_i then,

The resistance of the element under the mechanical arm can be written as

$$\frac{R_p}{x_t} \times x_i$$

Applying the voltage division rule we have,

$$e_o = \frac{\frac{R_p}{x_t} \times x_i}{R_p} \times e_i$$

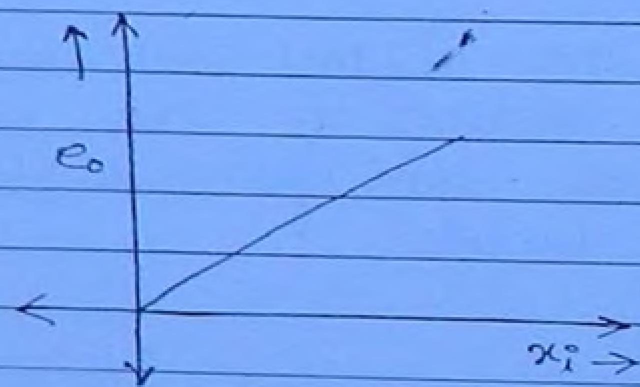
$$e_o = \frac{e_i}{x_t} \times x_i$$

114

Taking the sensitivity we have

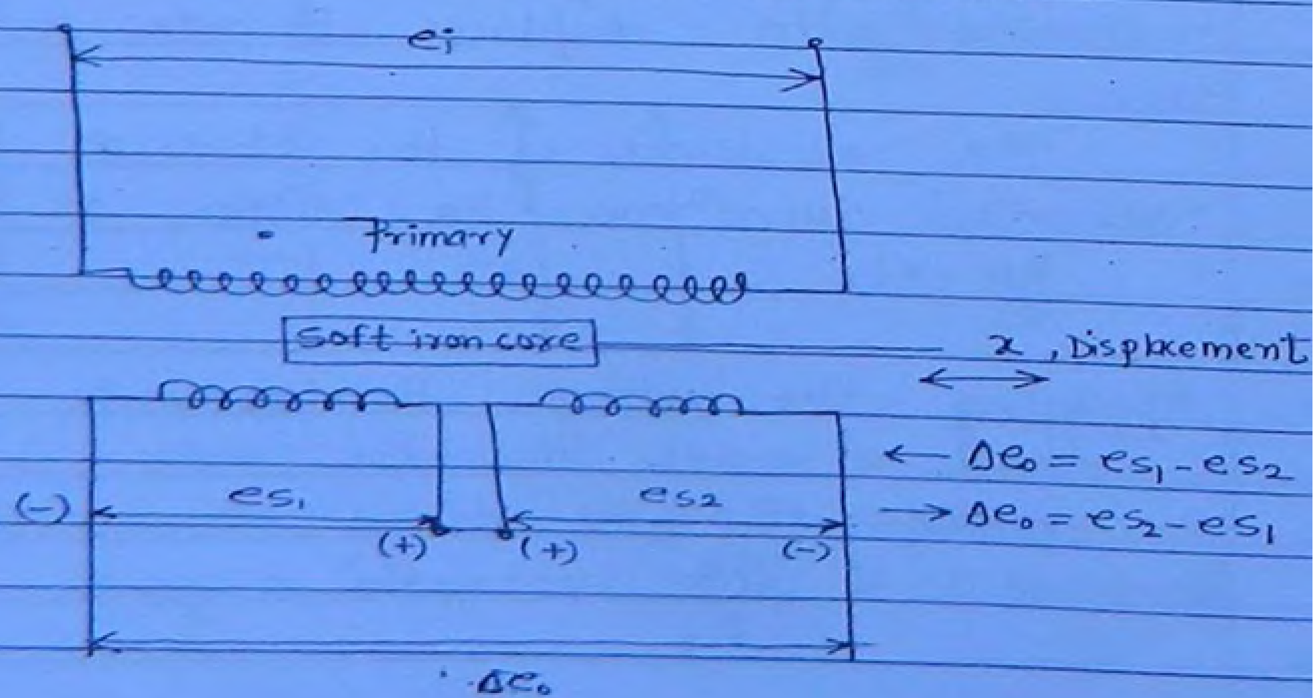
$$\frac{\partial e_o}{\partial x_i} = \frac{e_i}{x_t} = K \quad \text{(Potentiometer gain)}$$

$$e_o \propto x_i$$



Variable L Transducers

* Linear Variable Differential Transformer :



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1. The linear Variable differential transformer (LVDT) is a variable inductance based transducer that senses the displacement under measurement in terms of a change in its mutual inductance

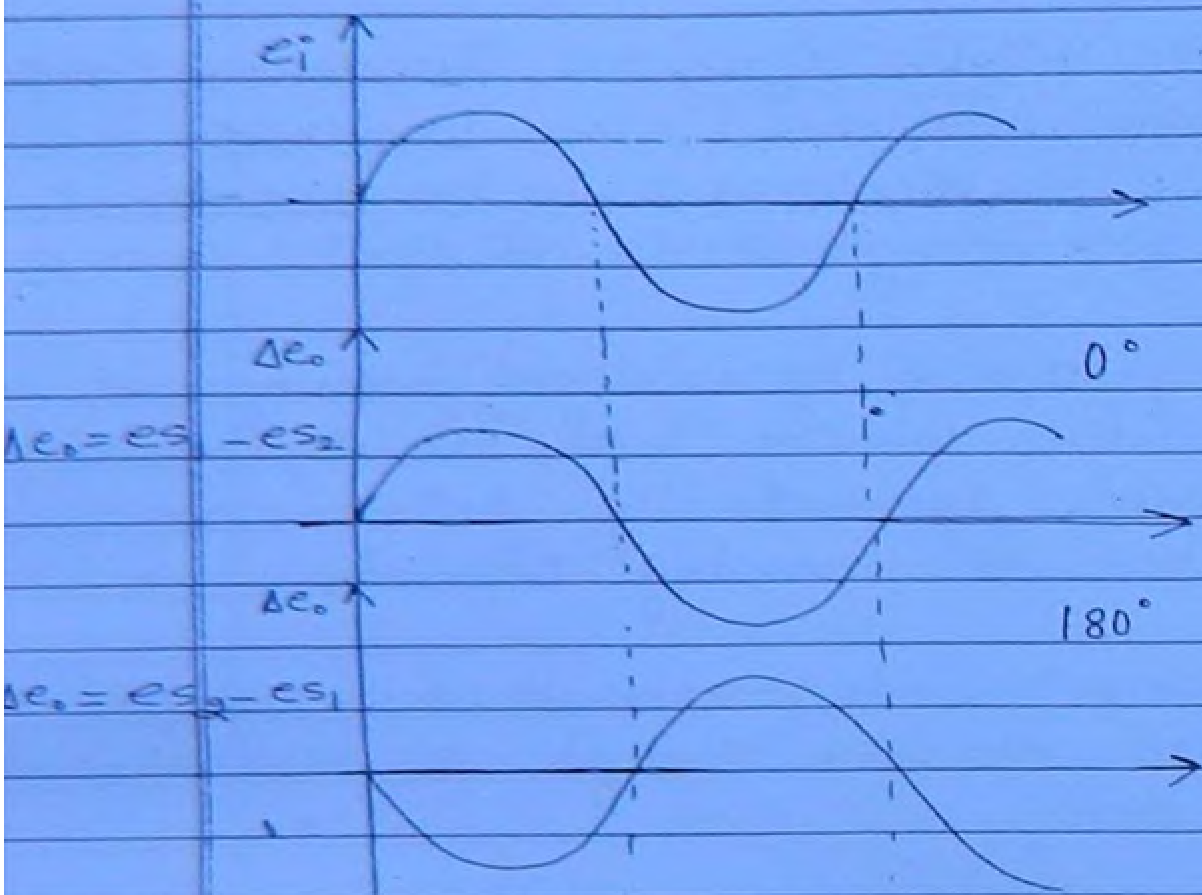
2. It basically consists of a single primary and two secondary windings with the soft iron core placed symmetrically between the primary and the secondary windings.

3. The displacement under measurement is applied to the soft iron core through the mechanical linking arm.

4. This displacement causes the soft iron core to move in the area between the primary and secondary windings, resulting in voltages being induced in the two secondary terminals.

5. In order to obtain a differential output, the two secondary terminals of the LVDT are shorted in the series opposition methodolog (-ve to -ve, +ve to +ve).

6. The differential o/p Δe_0 obtained at the differential terminal differs in phase with the i/p by either 0° or 180° depending on the direction in which the core is displaced.



-7. If the Core is placed symmetrically between two secondary terminals S_1 & S_2 then the voltages es_1 and es_2 will be equal and the differential o/p Δe_0 will be equal to zero.

-8. But in practical LVDT a small amount of differential voltage is always observed across the differential terminals of LVDT due to the presence of stray or residual flux in the area.

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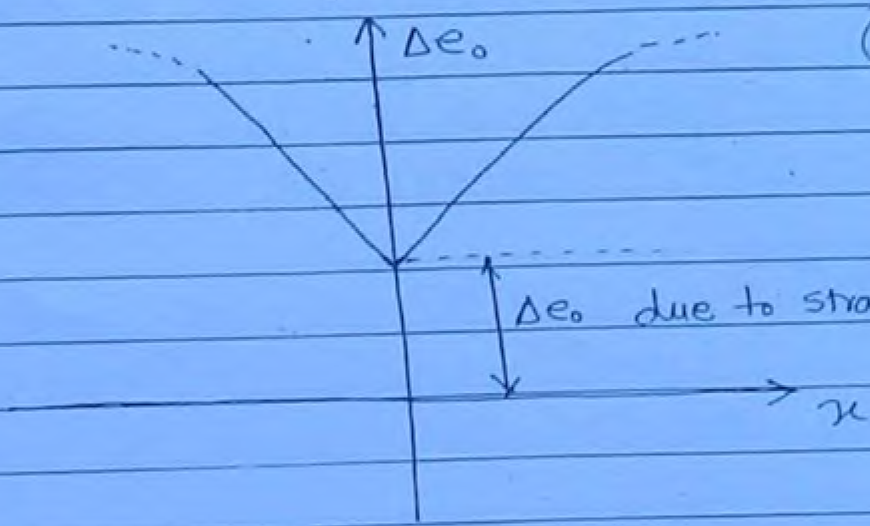
-9. The effect of this stray or residual flux is easily observed from the i/p - o/p characteristic of the LVDT shown below:

117



-10. The magnitude of the differential voltage due to the stray flux can be minimized by using a core made up of a Ni-Fe alloy heat treated in presence of Hydrogen.

characteristics of an LVDT:

1. Highly linear i/p - o/p relationship.
2. The transducer is highly sensitive over a wide range of motion.
3. One of the most widely used transducers for the measurement of displacement.

Q1. An ac-LVDT is given a 6.3V i/P and produces 5.2V for a range of ~~of~~ ± 0.5 inch displacement. When the Core is -0.25 ~~-2.5~~ inch from the Centre, what is the o/P produced?

Soln:

$+0.5$ inch $\longrightarrow$ 5.2

-0.25 inch $\longrightarrow$?

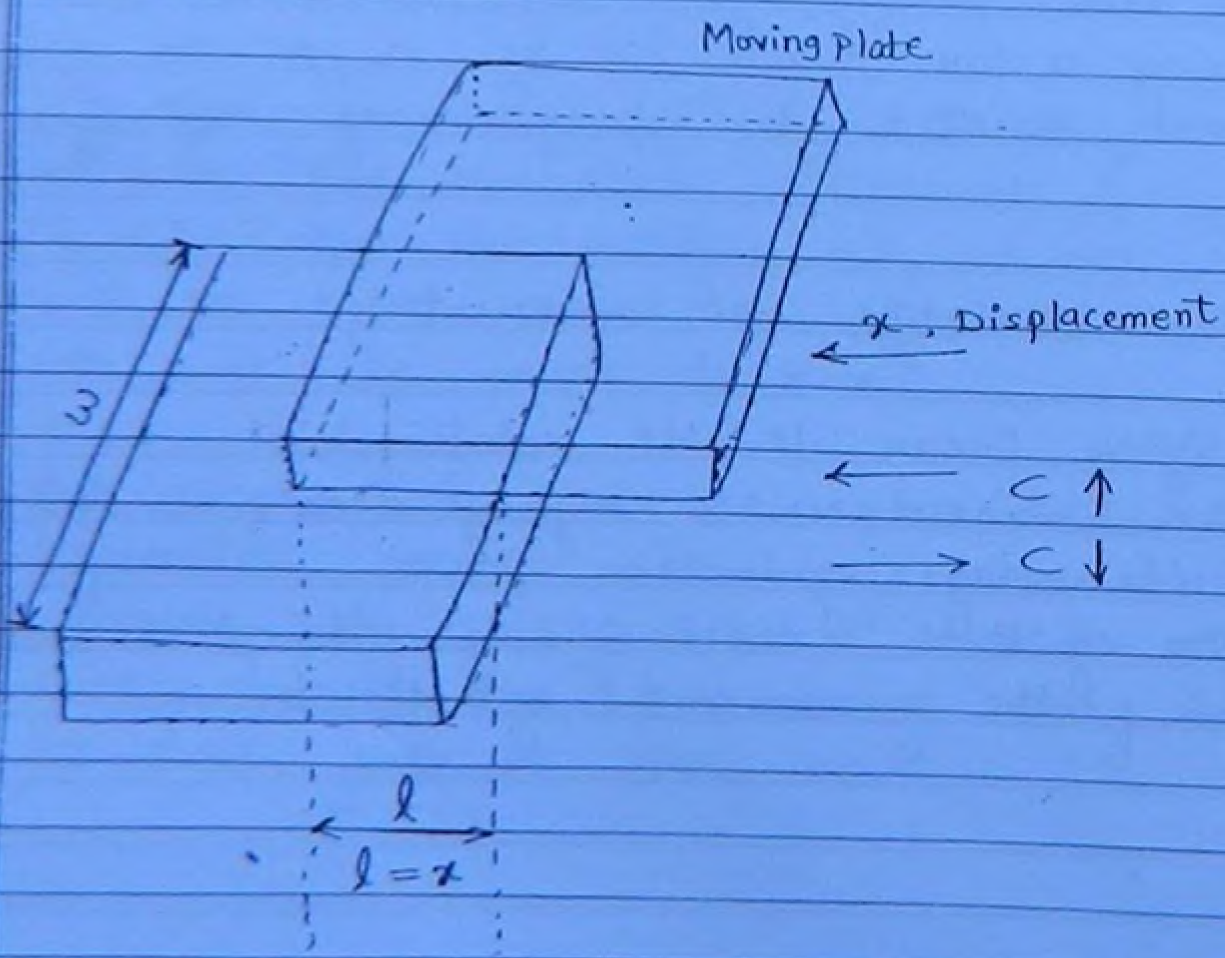
118

o/p of LVDT $x = \dfrac{-5.2 \times 0.25}{0.5} = -2.6\text{ V}$

$= -2.6\text{V}$

Variable C Transducers:

(i) With Variable Area:



-1. Variable capacitance base their operation on the expression for the capacitance of a parallel plate capacitor.

-2. These transducers can be designed for both change in area as well as the change in distance between the two plates.

-3. The above fig. shows the schematic of a variable capacitance transducer based on the change in area between the plates.

-4. It basically consists of 2 plates one of which is fixed and the other is moving.

-5. The displacement under measurement is applied to the moving plate which moves over the fixed plate, causing the overlapping distance between the fixed and the moving plates to change.

-6. This causes the effective area between the fixed and the moving plates to change resulting in a change in capacitance.

-7. The working of such a transducer is shown below.

we know,

$$C = \frac{\epsilon A}{d} \qquad (120)$$

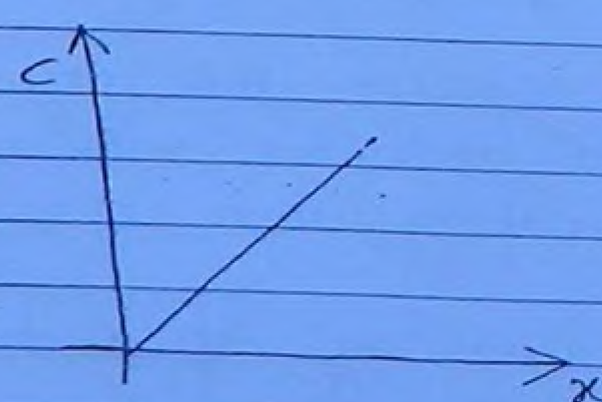
ϵ = Dielectric Strength
A = Area between plates $(l \times w)$
d = the distance between the plates.

As the displacement is applied to the moving plate, the overlapping distance between the fixed and the moving plate to change.

Taking the sensitivity we have,

$$\frac{\partial c}{\partial x} = \frac{\epsilon W}{d} = K \qquad \left(\frac{\epsilon W}{d} = K\right)$$

$$\therefore C \propto x$$



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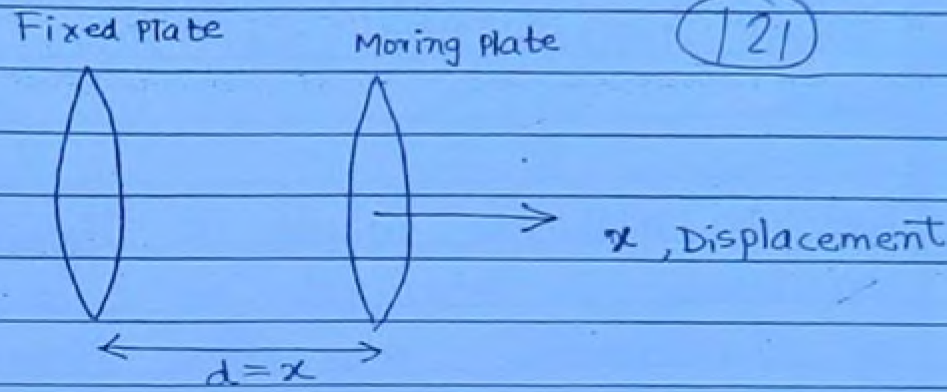
(ii) With variable distance:



121

- The above schematic shows a variable capacitance based on the change in distance between the plates.

Here,

$$C = \frac{\epsilon A}{d}$$

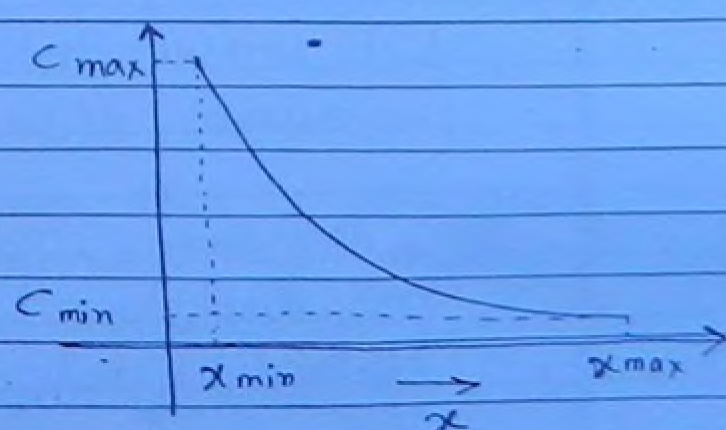
Where,

$d = x$, the displacement

$$\therefore C = \frac{\epsilon A}{x}$$

Taking the sensitivity

$$\frac{\partial C}{\partial x} = \frac{-\epsilon A}{x^2}$$



-2. from the above analysis it can be seen that these transducers give a hyperbolic i/p - o/p characteristic and hence are rarely used.

122

-3. But in instances where a high degree of sensitivity is required for a small range of displacement, then these transducers which base their operation on the change in distance between the plates are preferred over the one's which base their operation on the change in area between the plates.

Measurement of Pressure :

1. Pressure Measurement Using Passive Transducers :

Pressure transduction using passive transducer is a 2 stage process which involves

(i) Primary transducers or elastic element, which convert the sensed pressure into a proportional displacement.

(ii) Secondary transducers which convert the displacement into the proportional electrical signal.

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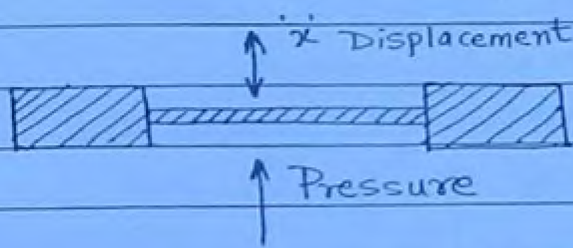
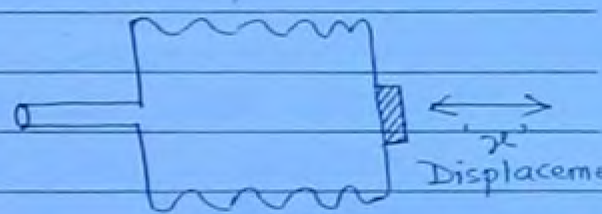
The various primary transducers used for pressure measurement are

(123)

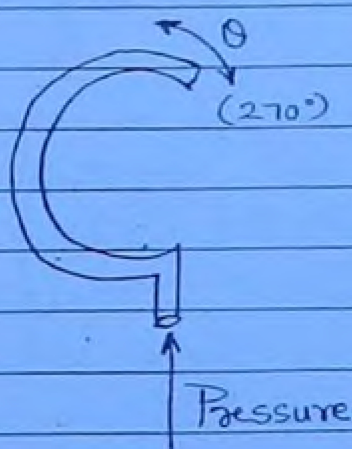
- (i) Diaphragm
- (ii) Bellows
- (iii) Bourdon Tubes
- (iv) Capsule



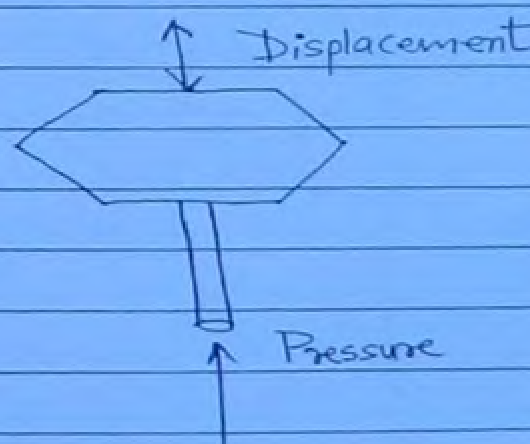
DIAPHRAGM



BELLOWS



BOURDON TUBE



CAPSULE

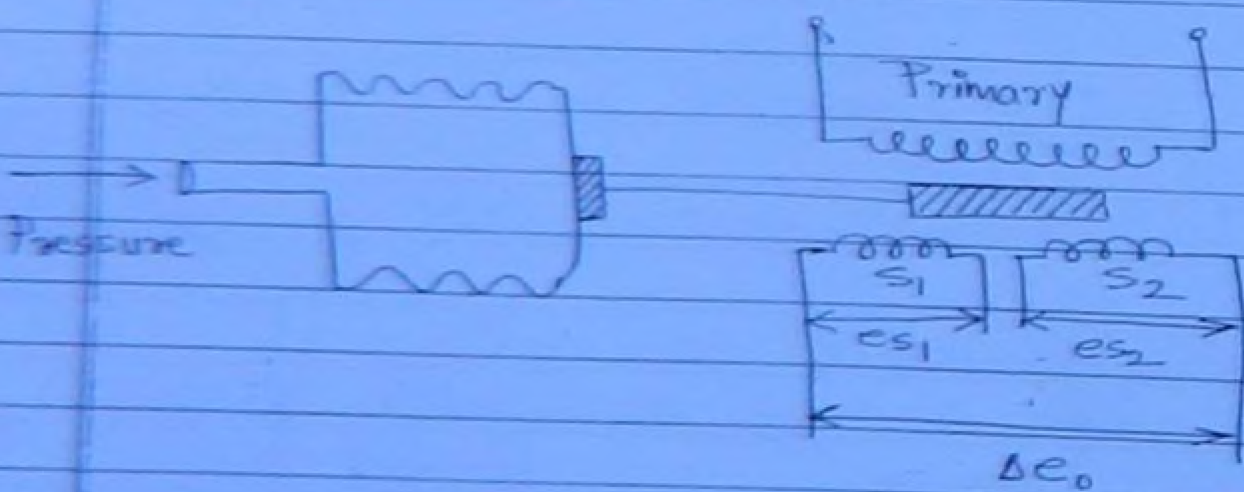
1. The Capsule is a device that is specifically used for the measurement of "dynamic pressure" whereas, the other 3 pressure transducers are specifically used for "static pressure measurement"

-2- Of all the transducers shown above, the o/p of the Bourdon tube is an angular displacement and hence these devices can directly be designed to work as 'Pressure Guages'.

124

-3- The primary transducers shown above are generally made up of Be-Cu, P-B Phosphor-Bronze or Stainless Steel.

-4- They are capable to measure pressures ranging from a few mm of Hg to several atmospheres



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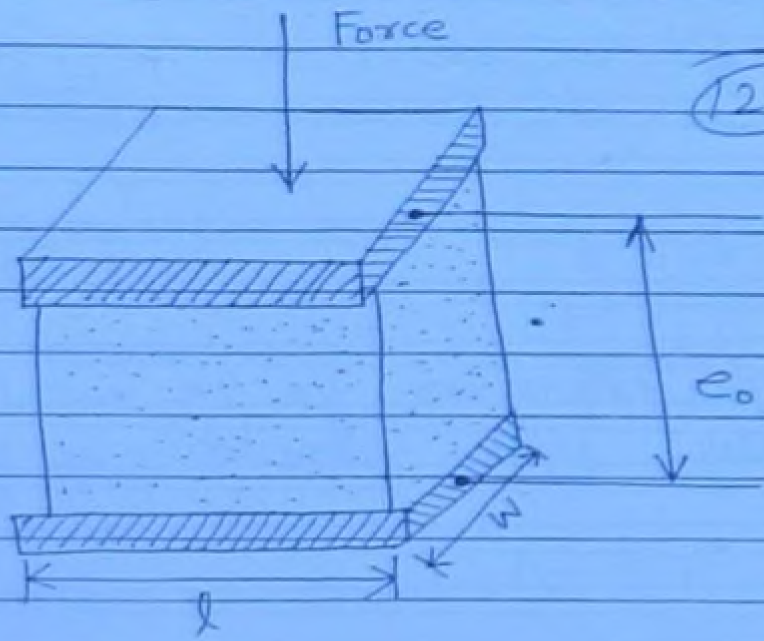
Measurement of Pressure using piezo-electric crystals:



Piezoelectric effect is the one, by the virtue of which the charges are induced across the certain surfaces of the crystal when its mechanical dimensions are changed due to the application of the pressure.

This is a reversible effect and materials which exhibit this property are: Quartz crystal Rochelle salt, Barium titanate.

By the Piezoelectric effect we have,

$$Q \propto F$$

$$Q = dF \quad \{d \rightarrow \text{charge Sensitivity}\} \quad -(1)$$

Considering the crystal to be a parallel plate capacitor the charge Q can be expressed as,

$$Q = CV$$

DATE : / /

In this case we have,

$$Q = C_p \times e_0$$ (126)

and,

$$e_0 = \frac{Q}{C_p} \quad \text{--- (2)}$$

From the expression for the capacitance of a parallel plate capacitor we have,

$$C_p = \frac{\epsilon A}{d}$$

In this case 'd' is the thickness of the crystal

$$C_p = \frac{\epsilon A}{t} \quad \text{--- (3)}$$

Substituting (3) and (1) in (2) we have,

$$e_0 = \frac{d \cdot F \cdot t}{\epsilon A}$$

Where,

$\frac{d}{\epsilon} = g$ (voltage sensitivity)

$\frac{F}{A} = P$ (pressure)

$t = t$ (thickness)

$$\therefore \quad e_0 = g \cdot p \cdot t$$

$$e_0 \propto p$$

(127) From the above analysis, it can be seen that the o/p of the piezoelectric crystal is directly proportional to the pressure applied.

One of the major limitations of this transducer is that it is specifically useful for the measurement of dynamic pressure only.

Measurement of Strain:

Expression for the Gauge factor of a strain guage:

we have,

$$R = \frac{\rho L}{A}$$

taking log on both sides,

$$\log R = \log L - \log A + \log \rho$$

Differentiating the above expression w.r.t stress (σ) we have,

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{L}\frac{dL}{d\sigma} - \frac{1}{A}\frac{dA}{d\sigma} + \frac{1}{\rho}\frac{d\rho}{d\sigma}$$

Here,

$$A = \frac{\pi D^2}{4} \quad \text{and} \quad \frac{dA}{d\sigma} = \frac{\pi D}{2}\frac{dD}{d\sigma}$$

$$\therefore \frac{1}{A}\frac{dA}{d\sigma} = \frac{4}{\pi D^2} \cdot \frac{\pi D}{2} \cdot \frac{dD}{d\sigma}$$

$$= \frac{2}{D}\frac{dD}{d\sigma}$$

128

Substituting the value of $\frac{1}{A}\frac{dA}{d\sigma}$ from above in eq – ①
we have,

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{L}\frac{dL}{d\sigma} - \frac{2}{D}\frac{dD}{d\sigma} + \frac{1}{\rho}\frac{d\rho}{d\sigma}$$

For small Variations, the above expression can be written as,

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - 2\frac{\Delta D}{D} + \frac{\Delta \rho}{\rho} \quad \text{—②}$$

from possion's ratio we have,

$$\nu = \frac{-\Delta D/D}{\Delta L/L},$$

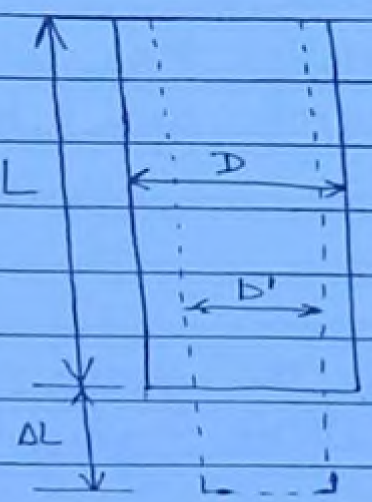
$$-\frac{\Delta D}{D} = \nu \cdot \frac{\Delta L}{L}$$

expression –② now can be written as,

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$

$$\frac{\Delta R}{R} = \left(1 + 2\nu + \frac{\Delta\rho/\rho}{\Delta L/L}\right)\frac{\Delta L}{L}$$

129



Stress (σ)

Strain $= \frac{\Delta L}{L}$

(microstrain)

objective:

$$\frac{\Delta R}{R} = \underbrace{K}_{\text{Guage factor}} \frac{\Delta L}{L}$$

1. The expression $\left(1 + 2\nu + \frac{\Delta\rho/\rho}{\Delta L/L}\right)$ is known as the generalized expression for the guage factor of the strain guage.

2. For metal wire strain guages, which exhibit a change in resistance due to the change in mechanical dimensions. The term $\frac{\Delta\rho/\rho}{\Delta L/L}$ will be 'zero' and hence $\frac{\Delta R}{R} = (1 + 2\nu)\frac{\Delta L}{L}$. Where, $(1+2\nu)$ is known as the guage factor of a metal wire "strain guage"

3. Typical values of the guage factor of a metal

wire strain guage vary from −3 to +5.

-4. In Semiconductor strain guages, where the change in resistance is due to the change in resistivity the term $(1+2\nu)$ will be equal to 'zero' and hence

$$\frac{\Delta R}{R} = \Delta\rho/\rho$$

130

-5. Typical values of the guage factor of a Semiconductor strain guage vary from 500 to 3000.

Q1. The strain guage bridge measures the strain in a Canti-lever were the guage is fixed. With strain ϵ, the guage resistance increases from 110 Ω to 110.52 Ω. If the guage factor is 2.30 then the strain in the Cantilever will be

Soln:

$$\frac{\Delta R}{R} = (1+2\nu)\frac{\Delta L}{L}$$

$$\therefore \frac{\Delta L}{L} = \frac{\Delta R}{R(1+2\nu)}$$

$$\frac{\Delta L}{L} = \frac{0.52}{110(2.30)}$$

$$\therefore \frac{\Delta L}{L} = 2.055 \times 10^{-3}$$

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Q2 The resistance strain guage is fasten to a beam subjected to a strain of 1×10^{-6}, yielding a resistance of 240 μΩ. If the original resistance of the strain guage is 120Ω the guage factor would be.

[3]

Soln:

$$\frac{\Delta R}{R} = \underset{\downarrow K}{(1+2V)}\frac{\Delta L}{L}$$

$$K = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}}$$

$$= \frac{}{1\times10^{-6}}$$

Q3 A strain guage with a guage factor of 2 is fasten to a stress of $10^{5}\times10^{4}$ KN/m^2. If the modulus of elasticity of steel is 2.1×10^{8} KN/m^2 then the change of resistance due to stress in the strain gudge is.

Imp

Soln: $K = 2$, Stress $= 10.5\times10^{4}$

$Y = 2.1\times10^{8}$

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{10.5\times10^{4}}{\text{Strain}}$$

$$\therefore \text{Strain} = \frac{10.5\times10^{4}}{2.1\times10^{8}}$$

$$= 5\times10^{-4}$$

PAGE :
DATE :

$$\frac{\Delta R}{R} = K \frac{\Delta L}{L}$$

$$= 2 \times 5 \times 10^{-4}$$ 132

$$\therefore \frac{\Delta R}{R} = 10^{-3}$$

DATE : / /

Measurement of Resistance :

obj / ES/PSU Introduction (131)

obj / ES/PSU Measurement of Medium R

** conv/obj / ES/PSU Measurement of Low R

obj/PSU Measurement of High R

Introduction :

Resistance measurement is characterized by the error due to the magnitude of the resistance being measured.

Thus, resistances are classified primarily on the basis of their magnitude as,

(a) Low resistance (less than 1Ω).
(b) Medium resistance (1Ω to $1M\Omega$).
(c) High resistance ($>1M\Omega$).

Measurement of Medium Resistance

The various methods for the measurement of medium resistance ~~classific~~ arranged as per the descending order of their accuracy are

1. Wheatstone's Bridge Method
2. Substitution Method
3. The Voltmeter - Ammeter Method
4. The ohm meter method.

134

Wheatstone's Bridge Method :

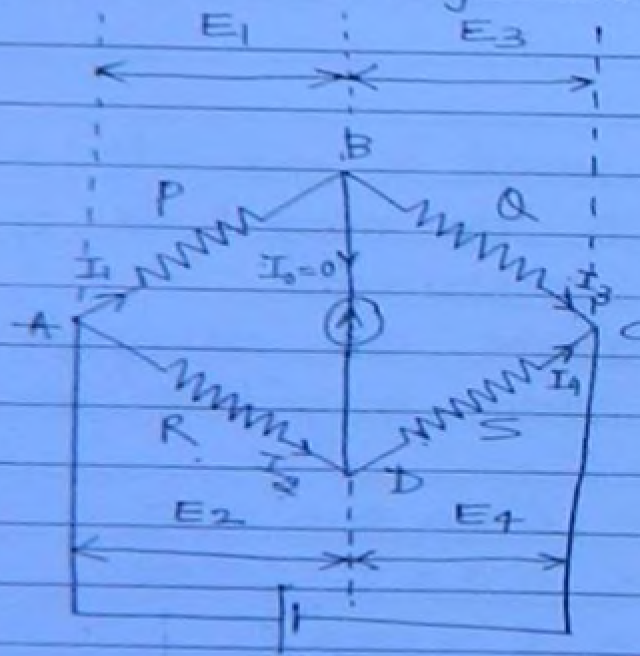
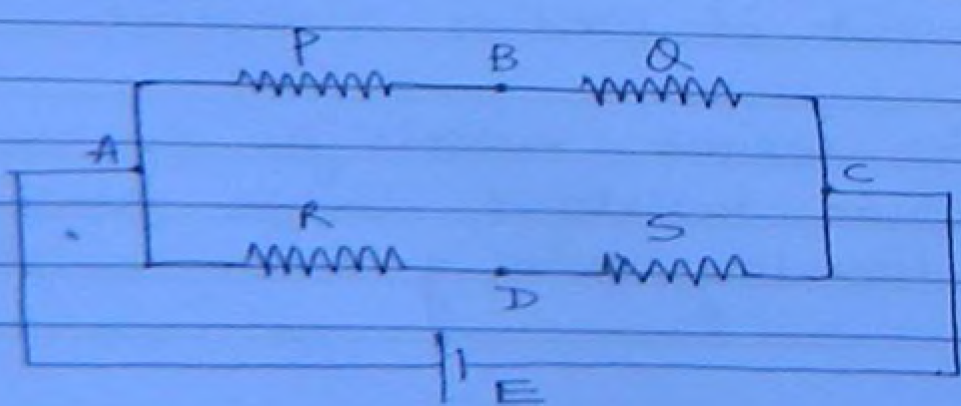


fig (1)



At Balance,

1. $I_D = 0$ (135)

2. $V_B = V_D$

3. $E_1 = E_2$ and $E_3 = E_4$

$I_1 P = I_2 R$

from fig (2) we have,

$$I_1 = \frac{E}{P+Q} \quad \text{and} \quad I_2 = \frac{E}{R+S}$$

$\therefore$ we have

$$\frac{P\cancel{E}}{P+Q} = \frac{\cancel{E}R}{R+S}$$

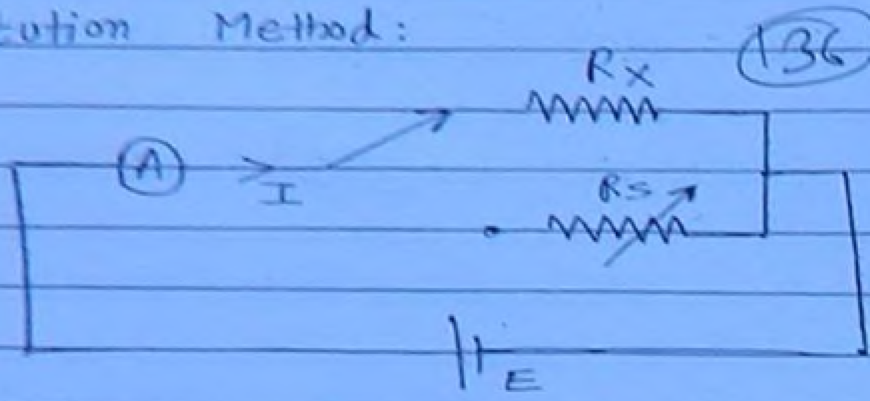
$$P(R+S) = R(P+Q)$$

$$PR + PS = PR + RQ$$

$$\therefore R = \frac{P}{Q}S$$

2. Substitution Method:

(136)

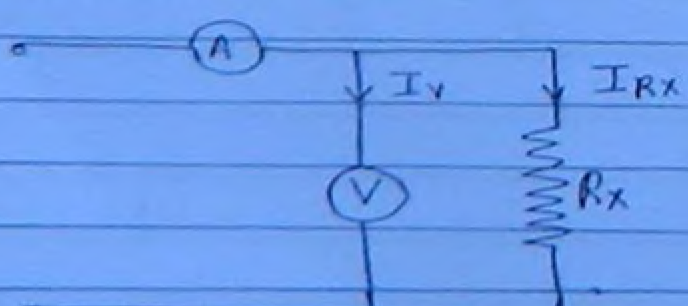


The Substitution method for the measurement of medium resistance bases its operation on the methodology of Comparison.

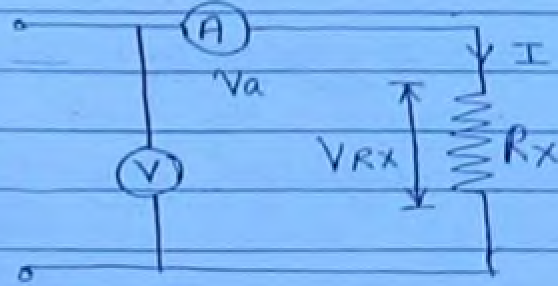
In this ckt, the value of an unknown resistance Rx is measured by Comparing it with a Standard resistance Rs in terms of the Current flowing through each of these resistances.

This method gives the measurement with a high degree of accuracy as its bases its operation on Comparison methodology

3. Voltmeter- Ammeter Method



(137)



-1. The value of an Unknown resistance R_x is calculated by an Voltmeter – Ammeter method on the basis of an expression $R = \frac{V}{I}$.

-2. In fig (2) where the ammeter is Connected along the unknown resistance, the error in the Calculated value would be due to the voltage drop across the ammeter ckt. (Power loss in the Ammeter).

-3. As the voltage drop increases with the increase in the Current drawn by Rs, this Connection methodology is Suitable for the measurement of high resistance which draw a negligible Current.

-4. In fig (1) where the ammeter is Connected on the supply side the error in the Calculated value is due to the Current through the voltmeter ckt.

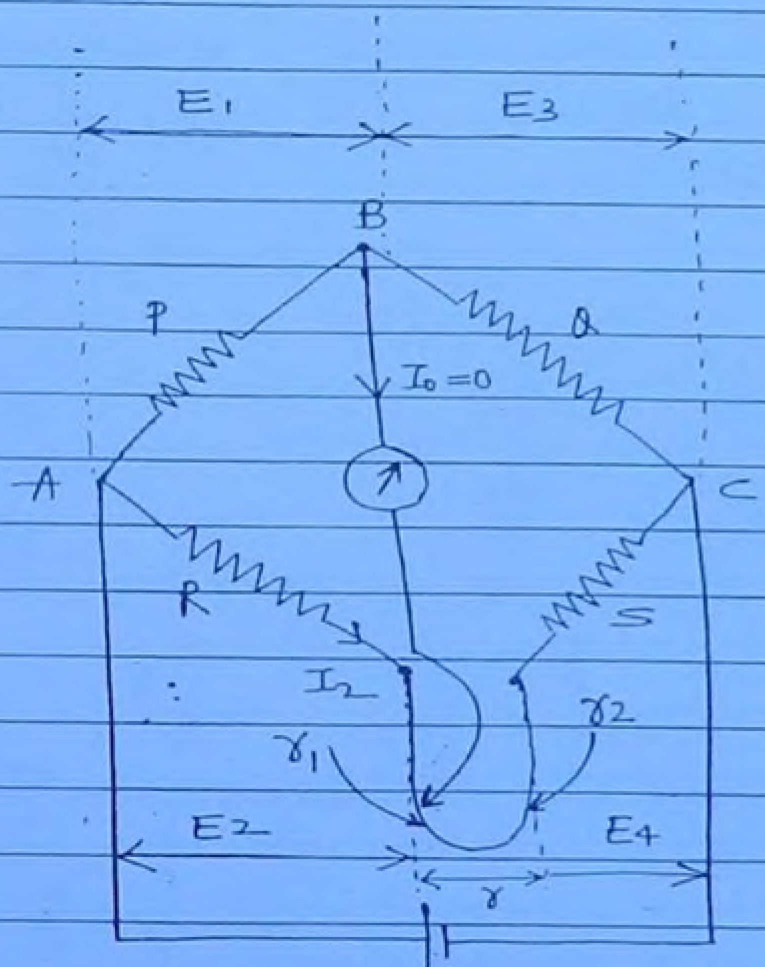
-5. If the Current drawn by the Unknown

resistance R_x is sufficiently large then the Current drawn by the voltmeter ckt. will be negligible due to its high resistance.

Thus, the ckt will be suitable for the measurement of low resistances which draw a large Current.

Measurement of Low Resistance:

Measurement of low resistance is characterised by the lead resistance effecting the ~~Ct~~ accuracy of the measurement. The effect of the lead resistance can be understood by a hypothetical Wheatstone bridge ckt shown below.



Ideally we have,

$$R = \frac{P}{Q} \cdot S \qquad \text{—— (1)}$$

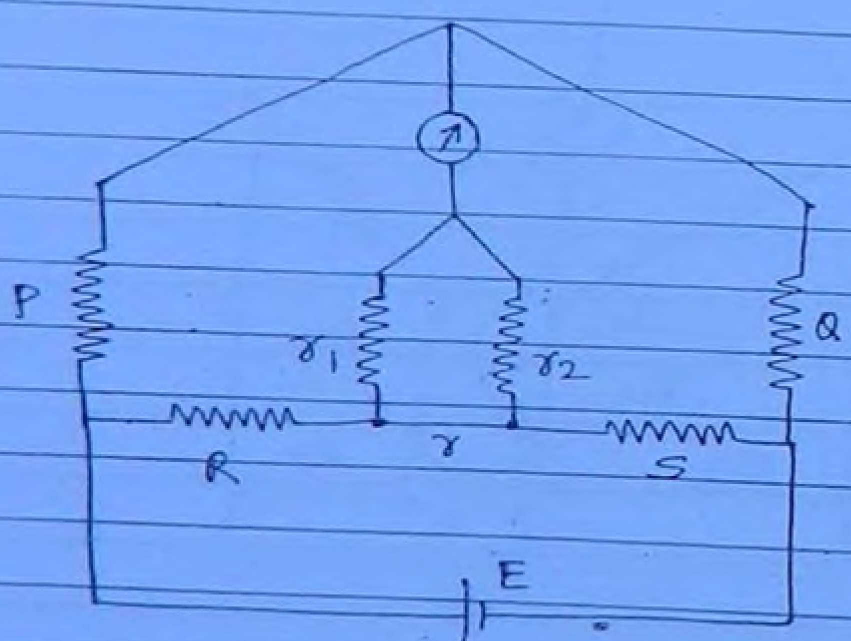
DATE: / /

Due to the effect of the lead resistance

$$(R+r_1) = \frac{P}{Q}(S+r_2) \quad \text{--- (2)}$$

(140)

The Wheatstone bridge is modified to form a Kelvin's double bridge ckt. in which an extra set of ratio arms are introduced under specific conditions in order to eliminate the effect of the lead resistance.



Conditions :

1. $\frac{P}{Q} = \frac{r_1}{r_2}$ --- (3)

2. $r_1 + r_2 = r$ --- (4)

PAGE :
DATE : / /

from eq – (3) we have,

$$\frac{P}{Q} = \frac{r_1}{r_2} \quad (4)$$

Adding on both sides we have,

$$\frac{P}{Q} + 1 = \frac{r_1}{r_2} + 1$$

$$\frac{P+Q}{Q} = \frac{r_1 + r_2}{r_2}$$

But as $r_1 + r_2 = r$

$$\frac{P+Q}{Q} = \frac{r}{r_2}$$ or,

or, $$r_2 = \frac{Q \cdot r}{P+Q} \quad \text{—} \quad (5)$$

Simillarly,

$$\frac{Q}{P} = \frac{r_2}{r_1}$$

Adding 1 on both sides,

$$\frac{Q}{P} + 1 = \frac{r_2}{r_1} + 1$$

$$\frac{Q+P}{P} = \frac{r_2 + r_1}{r_1}$$

As, $r_1 + r_2 = r$
we have,

142

$$\frac{Q+P}{P} = \frac{r}{r_1}$$

or, $$r_1 = \frac{Pr}{P+Q} \qquad \text{—(6)}$$

Substituting the value of (5) & (6) in (2)

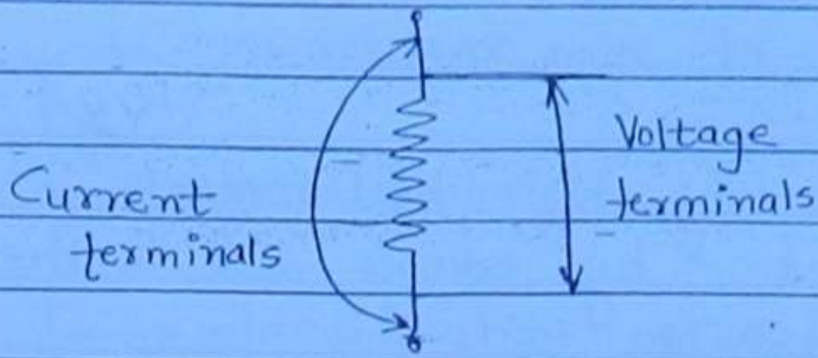
$$R + \frac{Pr}{P+Q} = \frac{P}{Q}\left(S + \frac{Qr}{P+Q}\right)$$

$$R + \cancel{\frac{Pr}{P+Q}} = \frac{PS}{Q} + \cancel{\frac{PQr}{Q(P+Q)}}$$

$$\therefore R = \frac{PS}{Q}$$

Thus, from the above analysis it can be seen that by introducing an extra set of ratio arms under the condition specified in eq-(3) and eq-(4) the effect of the lead resistances can be eliminated in a Kelvin's double bridge ckt.

Low resistances are generally fabricated as 4 terminal resistances as shown in fig.



143

Measurement of High Resistance :

(144)

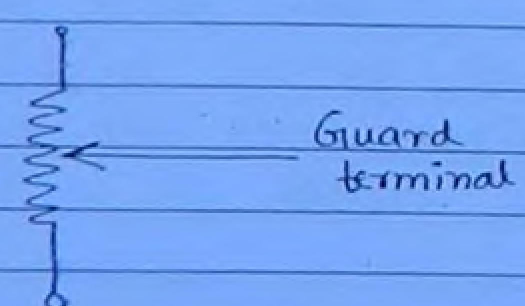
Measurement of high resistance is characterized by errors due to the leakage Currents.

The various methods for the measurement of high resistances arranged in the descending order of their accuracy are

1. Meg-Oh Bridge method.
2. Price guard wire Bridge method.
3. Loss of charge method.
4. Insulation testing Megger.

The insulation testing Megger is used for the measurement of the earth's resistance.

High resistances are generally fabricated as 3 terminal resistances as shown in fig.



: AC Bridges :

AC Bridges :

obj/psu

- → Introduction 145
- → classification of AC Bridges
- → Self Inductance Bridges
  - → Inductance Comparison bridge
  - * * * → Maxwell's Capacitance Comparison bridge
  - * * * → Hay's Bridge
  - * * * → Anderson's Bridge
  - → Owen's Bridge
- → Capacitive Bridges
  - → De Sauty's bridge
  - * * → Schering's bridge
- → Frequency Bridges
  - * * * → Wein's Bridge

An AC Bridge is a natural Outgrowth of the wheat's stone bridge and in effect contains 4 arms, a detector and a source.

The Various Sources used in the A.C bridge are

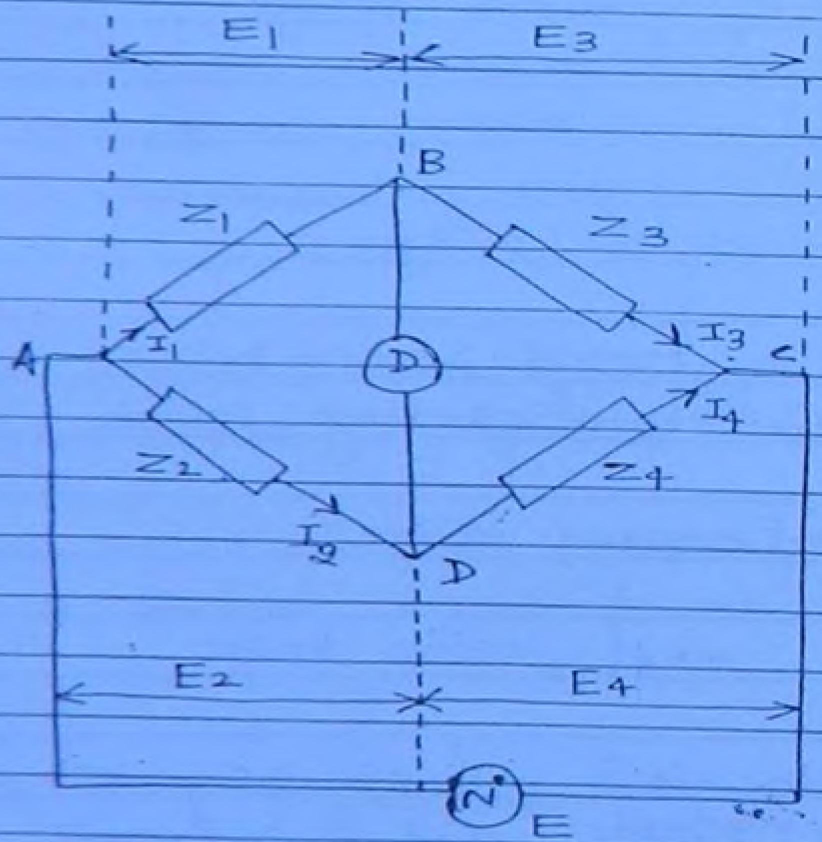
1. Power line Supply for normal to low freq^n appl^n.
2. Electronic Oscillators for high freq^n appl^n.

The Various detectors used in an A.C bridge are:

146

1. Telephone detector / Head phones (250 Hz – 4 KHz).
2. Vibrational Galvanometers (5 Hz – 1000 Hz).
3. Tunnable amplifier detectors (10 Hz – 10 KHz).
4. Cathode ray Oscilloscopes (for higher freq^n).

Note: Vibration Galvanometers are generally used as detectors below the 200 Hz range.



At Balance

1. $I_D = 0$

2. $V_B = V_D$

147

3. $E_1 = E_2$ and $E_3 = E_4$

$I_1 Z_1 = I_2 Z_2$

Here,

$I_1 = \frac{E}{Z_1 + Z_3}$; $I_2 = \frac{E}{Z_2 + Z_4}$

$\therefore \frac{\cancel{E} Z_1}{Z_1 + Z_3} = \frac{\cancel{E} Z_2}{Z_2 + Z_4}$

or, $Z_1 (Z_2 + Z_4) = Z_2 (Z_1 + Z_3)$

$\cancel{Z_1 Z_2} + Z_1 Z_4 = \cancel{Z_1 Z_2} + Z_2 Z_3$

$\therefore Z_1 Z_4 = Z_2 Z_3$

If Z is represented in the phase Magnitude form then for Converging balance we have,

$Z_1 \angle\theta_1 \cdot Z_4 \angle\theta_4 = Z_2 \angle\theta_2 \cdot Z_3 \angle\theta_3$

Imp

$\therefore Z_1 Z_4 = Z_2 Z_3$

$\angle\theta_1 + \theta_4 = \angle\theta_2 \cdot \theta_3$

for numerical this formula only will come

Representing Z in the rectangular Co-ordinate form we have,

148

$$(R_1 + jX_1)(R_4 + jX_4) = (R_2 + jX_2)(R_3 + jX_3)$$

In Order to obtain the Converging balance both the resistive and the reactive Component must be equal.

$$R_1R_4 - X_1X_4 = R_2R_3 - X_2X_3$$

$$R_1X_4 + X_1R_4 = R_2X_3 - X_2R_3$$

Bridges are classified on the basis of the parameter they measure.

149

PAGE :
DATE : / /

AC Bridges

Self Inductance Bridges

150

Maxwell's Inductance Comparison Bridge

Maxwell's Capacitance Comparison Bridge

- used for the measurement of medium Q- ($1 < Q < 10$)

Disadvantage - uses Variable capacitor for Comparison.

Hay's Bridge

- Modification of the Maxwell's capacitance Comparison Bridge
- Used for the measurement of high Q - Coils ($Q > 10$).

Anderson's Bridge

- Used for the measurement of low Q - coils ($Q < 1$).
- Modification of Maxwell's capacitance Comparison bridge.

Disadvantage - Balanced exp. difficult to obtain.

- can also be used for the measurement of Mutual Inductance or a capacitance.

Owen's Bridge

- Modification of Maxwell's Capacitance Comparison bridge
- used for measuring low Q - coils
- can also be used for measuring incremental inductance.

Capacitance Bridge

De Sauty's Bridge

- Can also be used for the measurement of lossless capacitance.

Schering Bridge

- Can also be used to measure dissipation factor.
- It is also used to measure the properties of insulators, insulating coils and capacitor bushings

Frequency Bridges

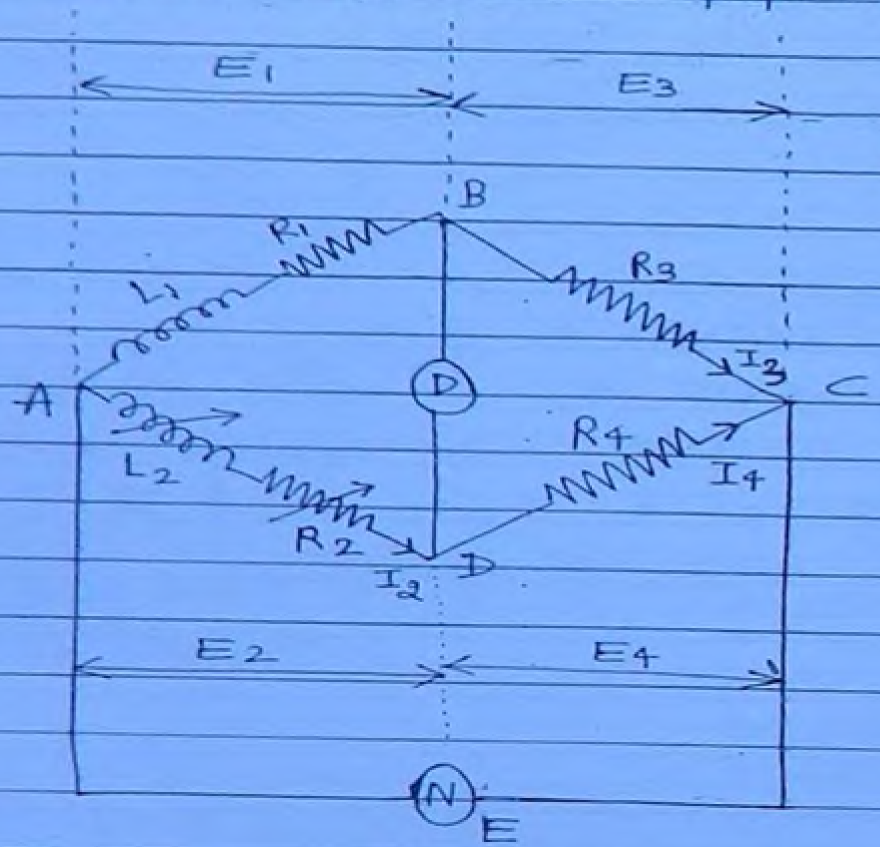
15

Wein's Bridge

- Can also measure a Capacitance.
- Finds applications as a frequency isolator in high frequency Oscillator and amplifier circuits.
- Also used as a Notch Filter in a total harmonic distortion analyzer.

Maxwell's Inductance Comparison Bridge :

152



The maxwell's Inductance Comparison Bridge measures the value of an Unknown self inductance in terms of a standard self inductance.

In the above ckt. diagram,

L_1 = Unknown self inductance with an internal resistance R_1.

L_2 = A standard variable self-Inductance

R_2 = A standard variable resistance.

DATE: / /

R_3, R_4 = fixed non-inductive resistances.

At Balance, (153)

$$Z_1 Z_4 = Z_2 Z_3$$

Where,

$$Z_1 = R_1 + j\omega L_1$$
$$Z_2 = R_2 + j\omega L_2$$
$$Z_3 = R_3$$
$$Z_4 = R_4$$

$$\therefore (R_1 + j\omega L_1)(R_4) = (R_2 + j\omega L_2) R_3$$

or, $$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega L_2 R_3$$

Separating and equating the real and imaginary components in the above expression, we have,

$$R_1 R_4 = R_2 R_3$$

$$\therefore R_1 = \frac{R_3}{R_4} R_2 \quad \text{——— (1)}$$

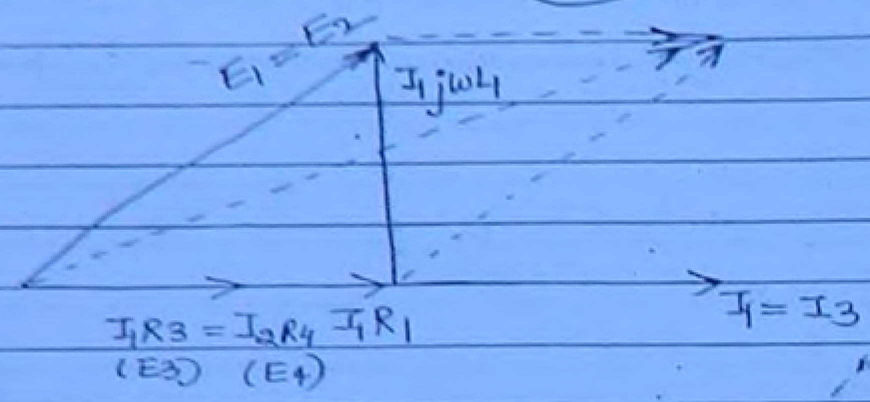
$$\cancel{j\omega} L_1 R_4 = \cancel{j\omega} L_2 R_3$$

$$\therefore L_1 = \frac{R_3}{R_4} L_2 \quad \text{——— (2)}$$

Note: This bridge is also known as the $\frac{L_1}{L_4}$ Bridge

Phasor diagram:

154



Procedure for drawing the Phasor Diagram:

1. The Current I_1 through the arm AB is taken as the reference and at balance $I_1 = I_3$ as $Id = 0$.

2. The voltage drop across resistance R_1 ($I_1 R_1$) will be in phase with I_1. and the voltage drop across L_1 ($I_1 j\omega L_1$) will lead I_1 by $90°$.

3. The phasor sum of $I_1 R_1$ and $I_1 j\omega L_1$ will be the voltage drop across arm AB (E_1) and at balance will be equal to the voltage drop across the arm AD (E_2). ($E_1 = E_2$).

4. The Voltage drop across the arm BC (E_3) i.e $I_3 R_3$ will be in phase with I_1 and at balance will be equal to the voltage drop

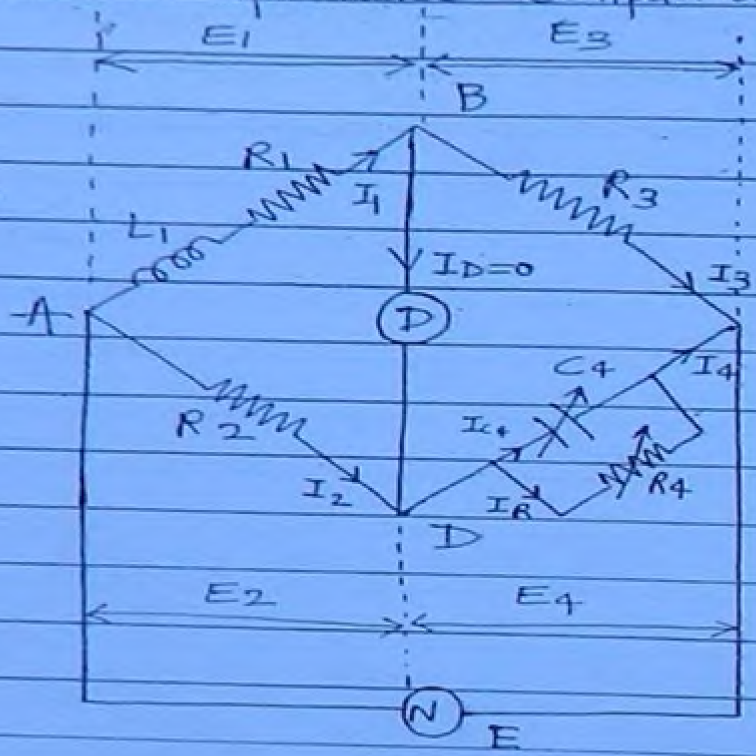
DATE : / /

across the arm CD (E_4) i.e ($I_2 R_4$) ($E_3 = E_4$).

5. The phasor sum of $E_1 = E_2$ and $E_3 = E_4$ is the supply voltage E.

153

Maxwell's Capacitance Comparison bridge:



The maxwell's capacitance bridge measures the value of an unknown self inductance in terms of an standard capacitance.

In the above ckt we have

L_1 = An Unknown self inductance with an internal resistance R_1.

R_2, R_3 = Fixed non-inductive resistances

C_4 = A standard variable capacitance.

R_4 = A standard variable Resistance

At balance we have,

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_1 = R_1 + j\omega L_1$$
$$Z_2 = R_2$$
$$Z_3 = R_3$$

$$Z_4 = \frac{R_4}{1 + j\omega C_4 R_4}$$

$$\therefore (R_1 + j\omega L_1)\frac{R_4}{(1 + j\omega C_4 R_4)} = R_2 R_3$$

$$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_2 R_3 R_4$$

Now,

Separating and equating real and imaginary Components in the

$$\therefore \quad R_1 R_4 = R_2 R_3$$
$$R_1 = \frac{R_3 R_2}{R_4} \quad \text{——} \; (1)$$

and,

$$j\omega L_1 R_4 = j\omega C_4 R_2 R_3 R_4$$
$$\therefore L_1 = C_4 R_2 R_3 \quad \text{——} \; (2)$$

We know that,

$$Q = \frac{\omega L_1}{R_1}$$
$$= \frac{\omega C_4 R_2 R_3 R_4}{R_3 R_2}$$
$$= \omega C_4 R_4$$

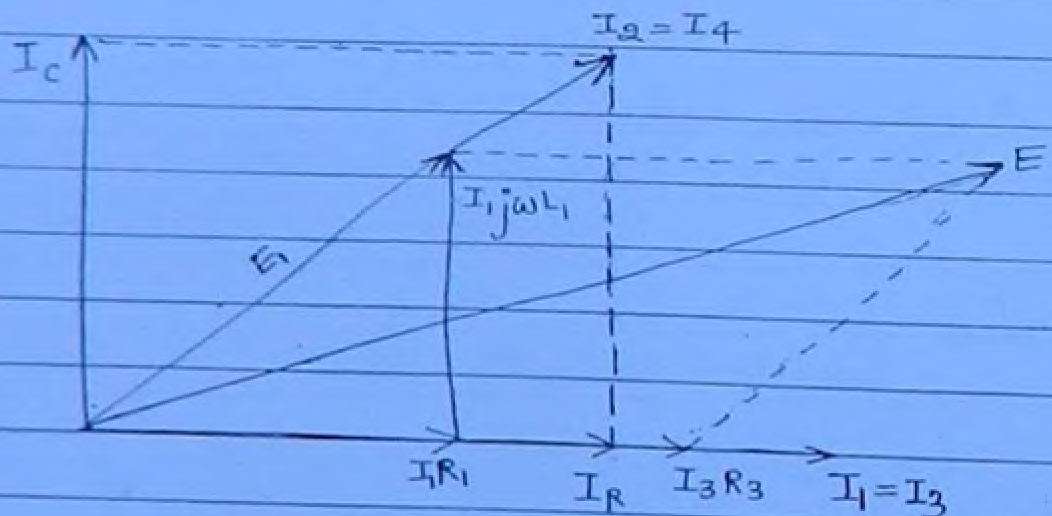
Note :

-1. This bridge is also known as the Maxwell's inductance capacitance bridge, the Maxwell Wein bridge, the $\frac{L}{C}$ bridge or the Maxwell's bridge

(158)

-2. This bridge is suitable for the measurement of medium values of Q $(1 < Q < 10)$.

-3. This biggest disadvantage of this bridge is that it uses a variable capacitance for comparison which is very expensive to procure at higher accuracies.



$$E_4 \left\{ \begin{array}{l} = \frac{I_c}{j\omega C_4} \\ = I_R R_4 \end{array} \right.$$

1. The Current I_1 through the arm AB is taken as the reference and at balance $I_1 = I_3$ as the detector Current $I_d = 0$

159

2. The voltage drop across the resistor R_1 $(I_1 R_1)$ will be in phase with I_1 and voltage drop across L_1 $(I_1 j\omega L_1)$ leads I_1 by 90°.

3. The phasor sum of $I_1 R_1$ and $I_1 j\omega L_1$ is the Voltage drop across the arm AB (E_1).

4. The voltage drop across the resistance R_3 $(I_1 R_3)$ will be in phase with I_1 and at balance will be equal to the voltage drop across arm CD. $\left(E_4 = \frac{I_c}{j\omega C_4} = I_R R_4\right)$.

Hence, $E_3 = E_4$.

5. The Current I_c through the capacitor C_4 leads the voltage drop across it by 90° and the Current I_R through the resistance R_4 will be in phase with the voltage drop across R_4.

6. The phasor sum of I_R and I_c is the Current through the arm CD (I_4) Which at balance will be equal to I_2, as $I_d = 0$.

7. The voltage drop across the arm AD $(I_2 R_2)$ will be in phase with I_2 and at balance

PAGE :
DATE : / /

will be equal to the voltage drop across the arm AB

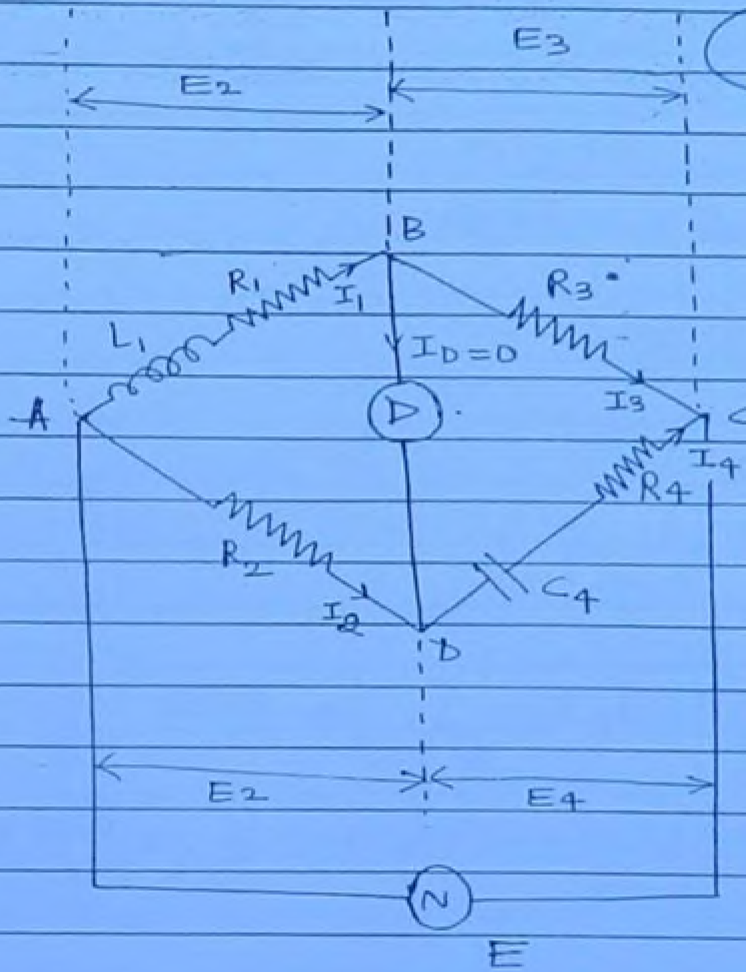
i.e, ($E_1 = E_2$)

160

The phasor sum of $E_1 = E_2$ and $E_3 = E_4$ is the supply voltage E.

HAY's Bridge (17-20 mks).

161



The Hay's bridge measure the value of an Unknown self Inductance in terms of a standard capacitance.

In the above fig. we have,

L_1 = Unknown self Inductance with an internal resistance R_1

R_2, R_3, R_4 = Fixed non-inductive resistances.

C_4 = A fixed standard capacitance.

At balance, 162
we have

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_1 = R_1 + j\omega L_1$$
$$Z_2 = R_2$$
$$Z_3 = R_3$$
$$Z_4 = \left(R_4 - \frac{j}{\omega C_4}\right)$$

$$\therefore \quad (R_1 + j\omega L_1)\left(R_4 - \frac{j}{\omega C_4}\right) = R_2 R_3$$

or, $$R_1 R_4 - \frac{jR_1}{\omega C_4} + j\omega L_1 R_4 + \frac{L_1}{C_4} = R_2 R_3$$

Separating and equating the real and imaginary components
we have,

$$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3 \quad \text{--- (1)}$$

$$\cancel{j}\omega L_1 R_4 = \cancel{j}\frac{R_1}{\omega C_4}$$

$$\omega L_1 R_4 = \frac{R_1}{\omega C_4}$$

$$L_1 = \frac{R_1}{\omega^2 C_4 R_4} \quad \text{--- (2)}$$

Substituting the value of L_1 from eq-(2) in eq-(1) and solving for R_1

we have,

163

$$R_1 R_4 + \frac{R_1}{\omega^2 C_4^2 R_4} = R_2 R_3$$

$$R_1 \left(R_4 + \frac{1}{\omega^2 C_4^2 R_4} \right) = R_2 R_3$$

$$R_1 \left(\frac{1 + \omega^2 C_4^2 R_4^2}{\omega^2 C_4^2 R_4} \right) = R_2 R_3$$

$$\therefore R_1 = \frac{\omega^2 C_4^2 R_2 R_3 R_4}{1 + \omega^2 C_4^2 R_4^2} \quad \text{--- (3)}$$

The value of L_1 is found by substituting exp-(3) in eq-(2)

$$L_1 = \frac{\cancel{\omega^2} C_4^{\cancel{2}} R_2 R_3 \cancel{R_4}}{(1 + \omega^2 C_4^2 R_4^2)\cancel{\omega^2} \cancel{C_4} \cancel{R_4}}$$

$$\therefore L_1 = \frac{C_4 R_2 R_3}{1 + \omega^2 C_4^2 R_4^2} \quad \text{--- (4)}$$

We know,

$$Q = \frac{\omega L_1}{R_1}$$

$$\therefore Q = \frac{\omega \cancel{C_4 R_2 R_3}}{\cancel{(1 + \omega^2 C_4^2 R_4^2)}} \cdot \frac{\cancel{(1 + \omega^2 C_4^2 R_4^2)}}{\omega^{\cancel{2}} C_4^{\cancel{2}} \cancel{R_2 R_3} R_4}$$

$$\therefore Q = \frac{1}{\omega C_4 R_4} \quad \text{--- (5)}$$

∴ The expression for L_1 can be now expressed as,

164

$$L_1 = \frac{C_4 R_2 R_3}{1 + \frac{1}{Q^2}}$$

if $Q > 10$; $1 + \frac{1}{Q^2} \cong 1$

$$\therefore L_1 = C_4 R_2 R_3 \quad — (6)$$

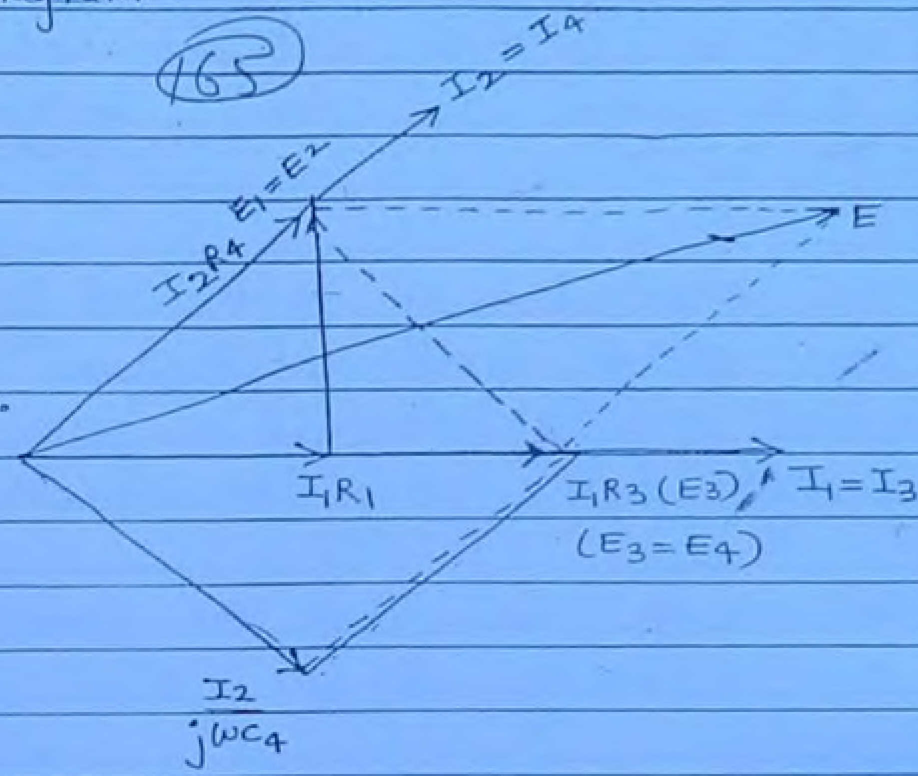
Note:

-1. The Hay's bridge is a modification of the Maxwell's Capacitance Comparison bridge.

-2. Balance in this bridge is obtained by replacing C_4 on a trial and error basis in order to reach the near balance Condition. A Variable resistance is placed in series with inductor L_1 and this resistor is tuned to obtain the final value

-3. This bridge is suitable for measurement of high Q-coils ($Q > 10$) for which it gives the simple expression for L_1.

Phasor Diagram:



Procedure:

1. The Current I_1 is taken as the reference and at balance $I_1 = I_3$, as $I_d = 0$.

2. The voltage drop across the resistance R_1 $(I_1 R_1)$. will be in phase with I_1 and the voltage drop across the inductance L_1 leads I_1 by 90°.

3. The phasor sum of $I_1 R_1$ & $I_1 j\omega L_1$ will be the voltage drop across the arm AB. Which at balance will be equal to the voltage drop across the arm AD as the points B & D are at equipotential. $(E_1 = E_2)$.

DATE : / /

-4. The voltage drop across the resistor R_4 (I_2R_4) will be in phase with I_2 and the voltage drop across the capacitor C_4 ($\frac{I_2}{j\omega C_4}$) will lag I_2 by 90°.

166

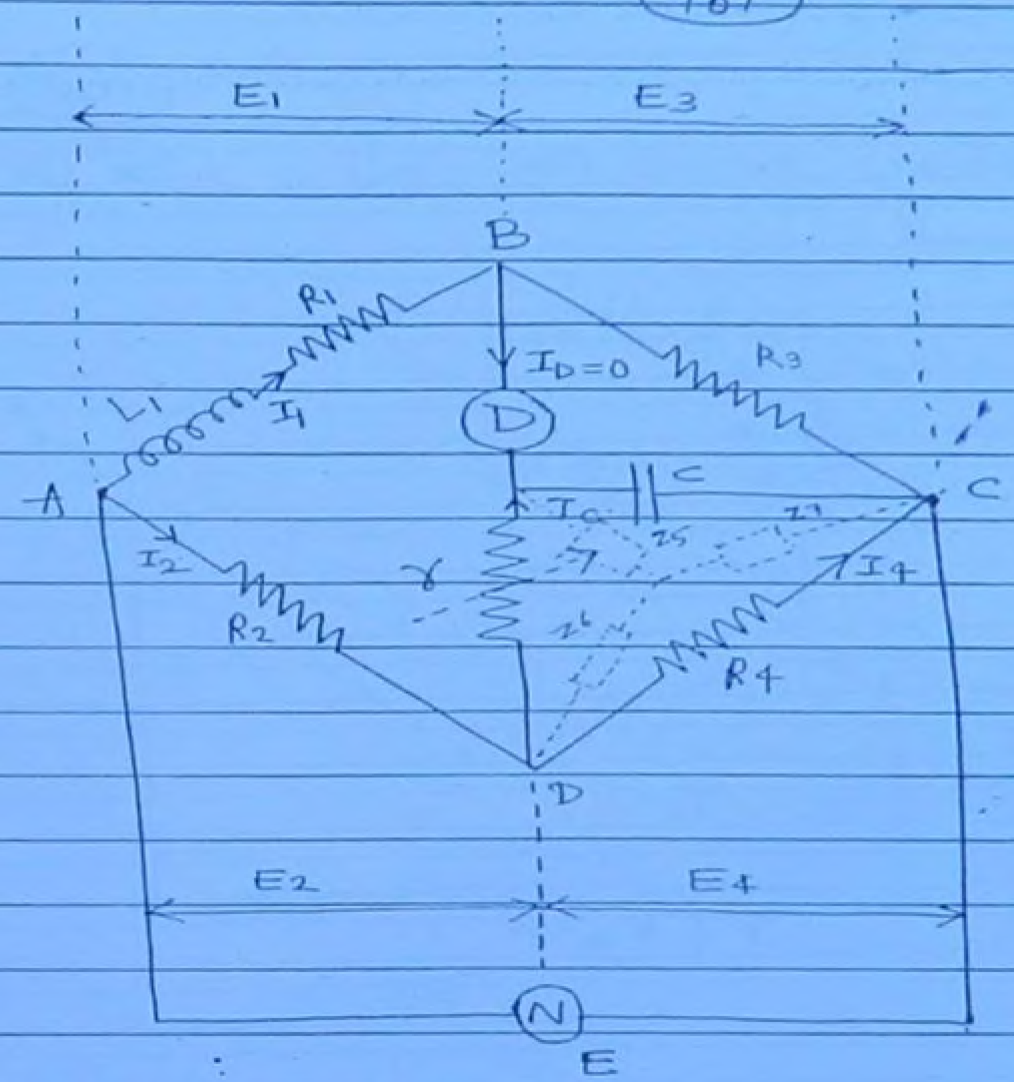
-5. The phasor sum of I_2R_4 and $\frac{I_2}{j\omega C_4}$ will be the voltage drop across arm CD (E_4). Which at balance will be equal to the voltage drop across the arm BC (E_3).

-6 The voltage drop across the arm E_3 will be in phase with I_1

-7. The phasor sum of $E_3 = E_4$ and $E_1 = E_2$ will be supply voltage E.

ANDERSON'S Bridge.

167



The Anderson bridge measures the value of an unknown self inductance in terms of a standard capacitance.

In the above fig. we have,

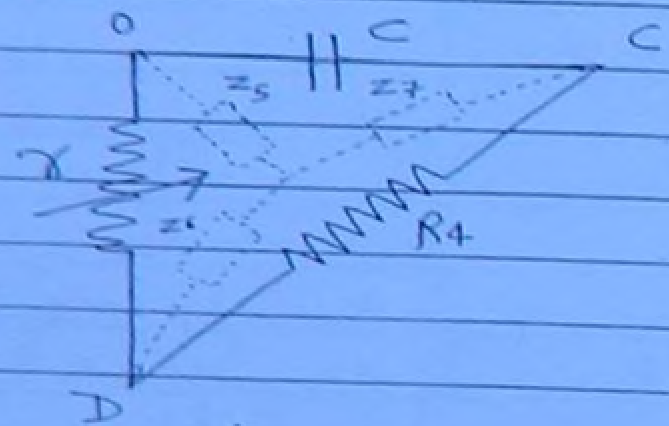
L_1 = The Unknown self Inductance with an internal resistance R_1.

R_2, R_3, R_4 = fixed non-inductive resistances.

C = A Standard fixed capacitance
r = A Standard variable resistance.

168

Converting the 'Δ' DOC into a 'star' we have,



Here,

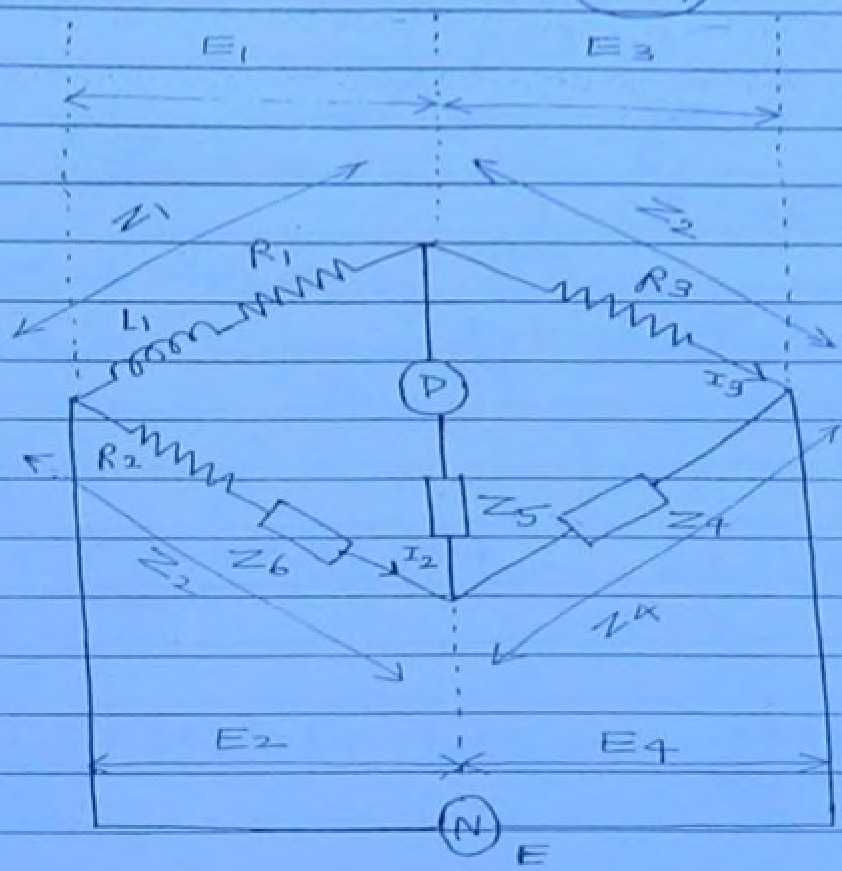
$$Z_5 = \frac{r \cdot \frac{1}{j\omega C}}{r + R_4 + \frac{1}{j\omega C}}$$

$$Z_6 = \frac{r \cdot R_4}{r + R_4 + \frac{1}{j\omega C}}$$

$$Z_7 = \frac{R_4 \cdot \frac{1}{j\omega C}}{r + R_4 + \frac{1}{j\omega C}}$$

Redrawing the Bridge,

(169)



At Balance we have,

$$Z_1 Z_4 = Z_2 Z_3$$

Where,

$$Z_1 = R_1 + j\omega L_1$$

$$Z_2 = R_2 + \frac{r R_4}{r + R_4 + \frac{1}{j\omega C}}$$

$$Z_3 = R_3$$

$$Z_4 = \frac{R_4 \cdot \frac{1}{j\omega C}}{r + R_4 + 1/j\omega C}$$

or, $\therefore \dfrac{(R_1 + j\omega L_1)\, R_4 \cdot \frac{1}{j\omega C}}{r + R_4 + \frac{1}{j\omega C}} = R_3\left(R_2 + \dfrac{r \cdot R_4}{r + R_4 + \frac{1}{j\omega C}}\right)$

170

or, $\dfrac{(R_1 + j\omega L_1)\, R_4 \cdot \frac{1}{j\omega C}}{r + R_4 + \frac{1}{j\omega C}} = R_2R_3 + \dfrac{rR_4R_3}{r + R_4 + \frac{1}{j\omega C}}$

or, $(R_1 + j\omega L_1)\dfrac{R_4}{j\omega C} = R_2R_3\left(r + R_4 + \dfrac{1}{j\omega C}\right) + rR_4R_3$

or, $(R_1 + j\omega L_1)\dfrac{R_4}{j\omega C} = rR_2R_3 + R_2R_3R_4 + \dfrac{R_2R_3}{j\omega C} + rR_3R_4$

or, $R_1R_4 + j\omega L_1R_4 = j\omega C rR_2R_3 + j\omega C R_2R_3R_4 + R_2R_3 + j\omega C rR_4R_3$

Seperating and equating real and imaginary parts in the above exp we have,

$$R_1R_4 = R_2R_3$$

$$\therefore R_1 = \frac{R_3}{R_4} \cdot R_2 \quad \text{--- (1)}$$

and,

$$\cancel{j\omega} L_1R_4 = \cancel{j\omega} C R_3(rR_2 + R_2R_4 + rR_4)$$

$$\therefore L_1 = \frac{CR_3}{R_4}\left(r(R_2 + R_4) + R_2R_4\right) \quad \text{--- (2)}$$

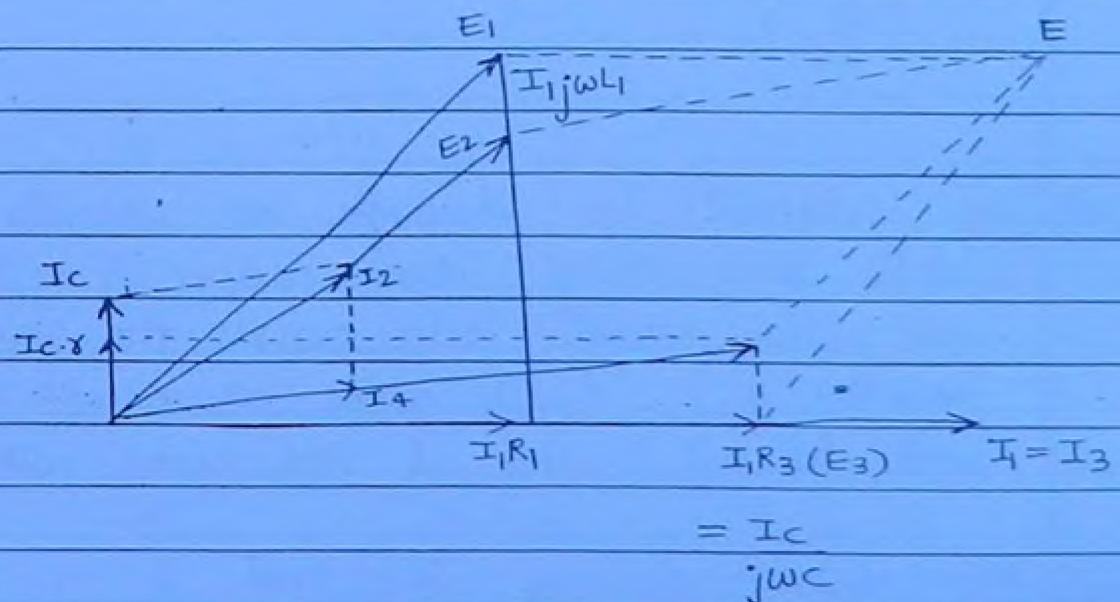
Note:

-1. The Anderson's bridge is a modification of the maxwell's capacitance Comparison bridge.

-2. This bridge is suitable for the measurement of low Q-Coils ($Q<1$).

-3. This bridge can also be designed to measure an Unknown Capacitance or a mutual inductance in terms of a standard self inductance.

Phasor Diagram:



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Procedure:

-1. The Current I_1 is taken as the reference and at balance $I_1 = I_3$ as the detector Current $Id = 0$.

172

-2. The Voltage drop across the resistance $R_1 (I_1 R_1)$ will be in phase with I_1 and the voltage drop across the inductor L_1 ~~lag~~ leads I_1 by 90°

-3. The phasor sum of $I_1 R_1$ and $I_1 j\omega L_1$ is the voltage drop across the arm AB (E_1).

-4. The Voltage drop across R3 $(I_1 R_3)$ will be in phase with I_1 and at balance will be equal to the voltage drop across the Capacitance C $\left(\frac{I_c}{j\omega C}\right)$.

-5 The Current I_c through the capacitor 'C' leads the voltage drop across it by 90° and the voltage drop across the variable resistor R will be in phase with I_c, as points D and O are at the same potential.

-6 The phasor sum of $I_c \cdot r$ and $\frac{I_c}{j\omega C}$ is the voltage drop across the arm CD $(I_4 R_4$ ie $E_4)$

PAGE :
DATE : / /

-7. The Current I_4 through the arm CD will be in phase with the voltage drop across it and the phasor sum of I_c and I_4 is the Current I_2.

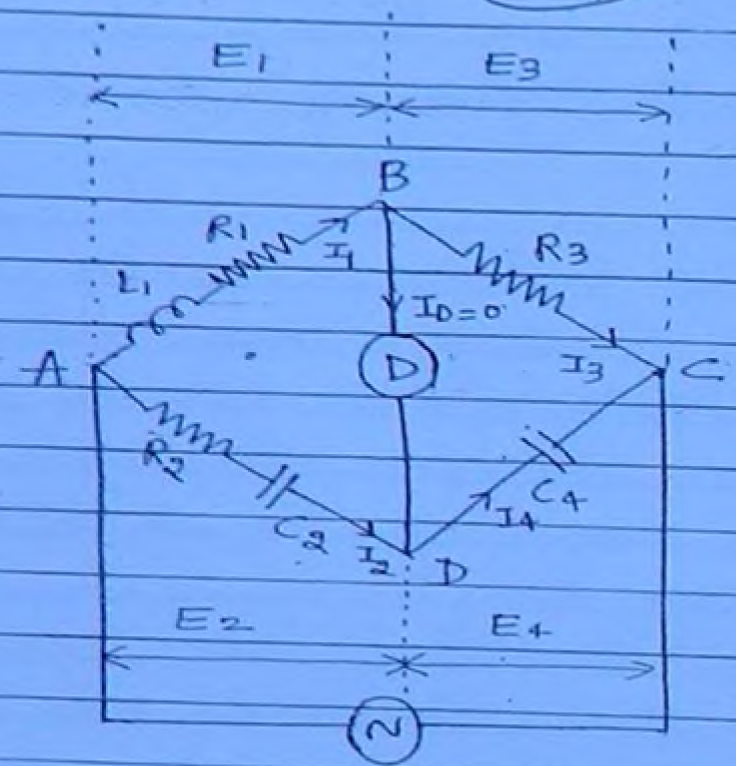
123

-8. As the arm AD Contains a purely resistive element, the Voltage drop across the resistance R_2 (I_2R_2 i.e E_2) will be in phase with I_2

-9. The phasor sum's of E_1, E_2, E_3 & E_4 is the Supply voltage E.

Owen's Bridge:

174



The Owen's bridge measures the value of an unknown self inductance in terms of a standard capacitance

In the above fig,
we have

L_1 = Unknown self inductance with an internal resistance R_1

R_2 = A standard Variable resistance.

C_2 = A standard Variable Capacitance.

DATE : / /

R_3 = A fixed non-inductive resistance.

C_4 = A fixed Standard Capacitance.

At balance we have, 125

$$Z_1 Z_4 = Z_2 Z_3.$$

Where,

$$Z_1 = R_1 + j\omega L_1$$

$$Z_2 = R_2 + \frac{1}{j\omega C_2}$$

$$Z_3 = R_3$$

$$Z_4 = \frac{1}{j\omega C_4}$$

$$\therefore (R_1 + j\omega L_1)\frac{1}{j\omega C_4} = \left(R_2 + \frac{1}{j\omega C_2}\right) R_3$$

or, $$\frac{R_1}{j\omega C_4} + \frac{L_1}{C_4} = R_2 R_3 + \frac{R_3}{j\omega C_2}$$

Separating and equating the real and imaginary parts in the above expression we have,

$$\frac{L_1}{C_4} = R_2 R_3$$

$$L_1 = C_4 R_2 R_3 \quad \text{—— (1)}$$

PAGE :
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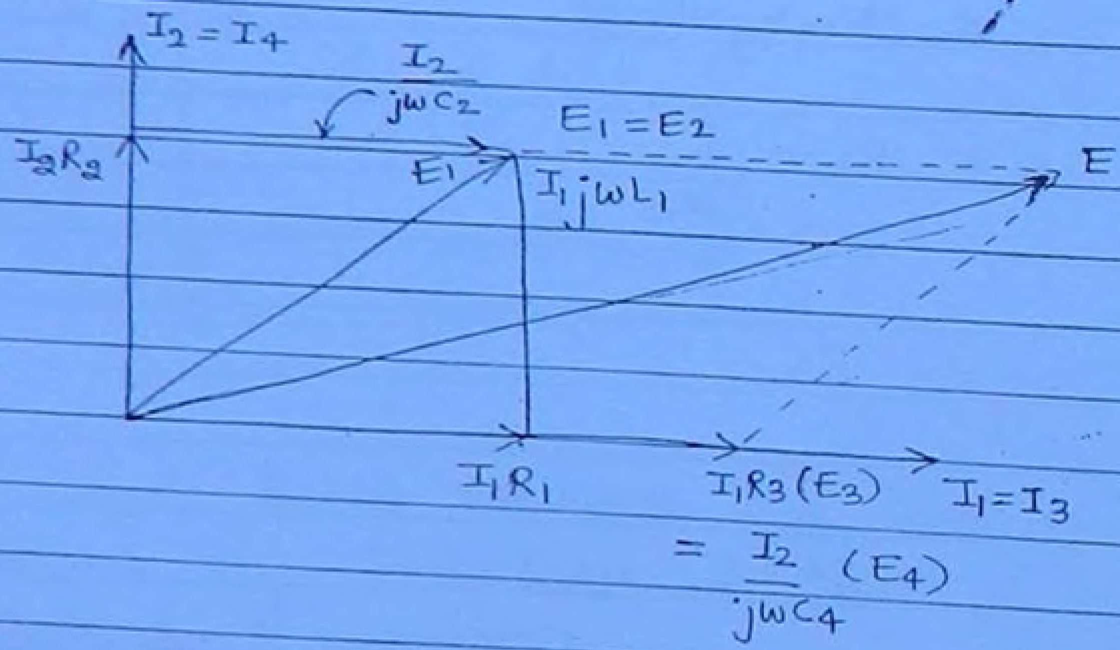
And,

$$\frac{R_1}{j\omega C_4} = \frac{R_3}{j\omega C_2}$$

T76

$$R_1 = \frac{C_4 R_3}{C_2} \quad \text{--- (2)}$$

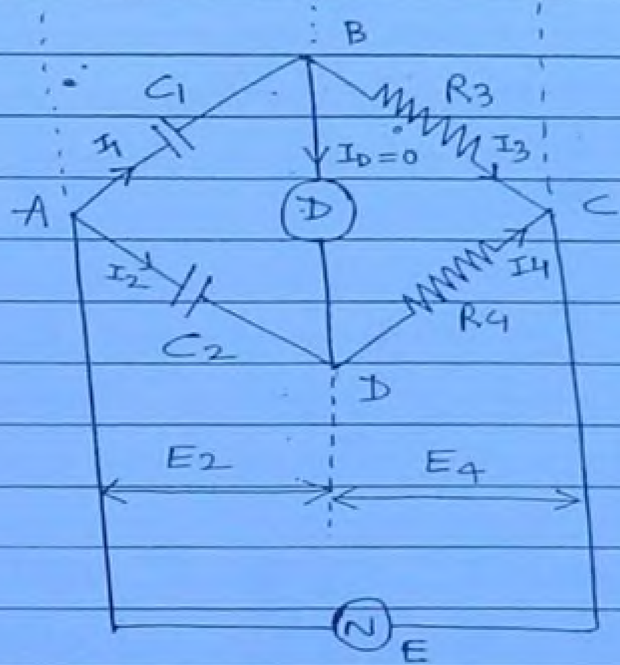
Phasor Diagram:



Capacitive Bridges :

De Sauty's Bridge :

177



The De - Sauty's Bridge measures the value of an unknown capacitance in terms of a standard capacitance

In the above fig, we have,

C_1 = Unknown Capacitance
C_2 = A fixed standard Capacitance
R_3, R_4 = A standard non-inductive resistances.

At Balance,
we have,

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_1 = \frac{1}{j\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2}$$

$$Z_3 = R_3$$

178

$$Z_4 = R_4$$

$$\therefore \frac{R_4}{\cancel{j\omega} C_1} = \frac{R_3}{\cancel{j\omega} C_2}$$

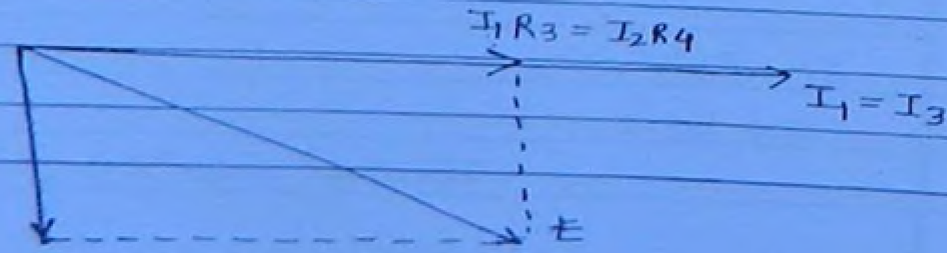
$$C_1 = \frac{R_4 C_2}{R_3} \quad \text{——— (1)}$$

Note :

1. The De-Sauty's bridge is used for the measurement of lossless capacitor only. (All air-cored and gas filled capacitors are loss-less capacitors).

2. Balanced is obtained in this bridge by either varying R_3 or R_4.

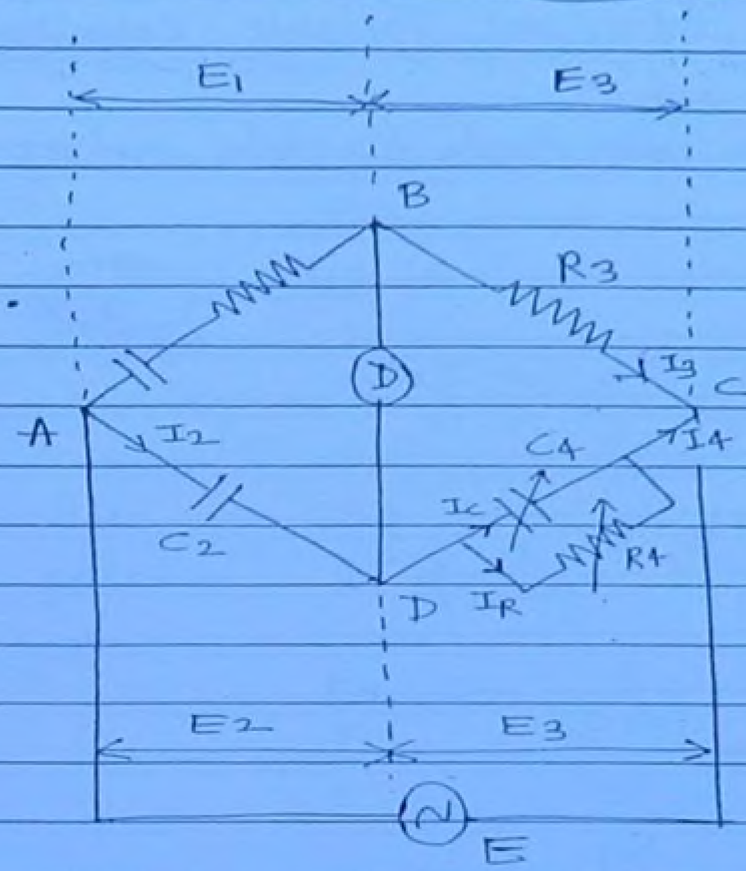
Phasor Diagram :



$(E_1 = E_2)$ $\frac{I_1}{j\omega C_1} = \frac{I_2}{j\omega C_2}$

Schering's Bridge

179



The Schering's Bridge measures the value of an Unknown Capacitance in Terms of a standard Capacitance.

In the above fig, we have

C_1 = Unknown capacitance, with its loss Component indicated as a series resistance R_1

C_2 = A fixed Capacitance.

DATE : / /

R_3 = fixed non-inductive resistance.

C_4 = A Standard Variable Capacitance.

R_4 = A Standard Variable resistance.

At balance,

180

$$Z_1 Z_4 = Z_2 Z_3$$

where,

$$Z_1 = \left(R_1 + \frac{1}{j\omega C_1}\right)$$

$$Z_2 = \frac{1}{j\omega C_2}$$

$$Z_3 = R_3$$

$$Z_4 = \frac{R_4}{1 + j\omega C_4 R_4}$$

$$\therefore \left(R_1 + \frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{R_3}{j\omega C_2}$$

or

$$R_1 R_4 + \frac{R_4}{j\omega C_1} = \frac{R_3}{j\omega C_2}(1 + j\omega C_4 R_4)$$

$$R_1 R_4 + \frac{R_4}{j\omega C_1} = \frac{R_3}{j\omega C_2} + \frac{C_4 R_4 R_3}{C_2}$$

DATE: / /

Separating and equating the real and imaginary Components in the above expression we have,

181

$$R_1 \cancel{R_4} = \frac{C_4 \cancel{R_4} R_3}{C_2}$$

$$R_1 = \frac{C_4 \cdot R_3}{C_2} \quad \text{———} \quad (1)$$

and,

$$\frac{R_4}{\cancel{j}\omega C_1} = \frac{R_3}{\cancel{j}\omega C_2}$$

$$C_1 = \frac{R_4 \cdot C_2}{R_3} \quad \text{———} \quad (2)$$

Note:

-1. The Schering's bridge finds applications in the measurement of various properties of insulators, insulating oil and Capacitor bushings.

-2. The dissipation factor of the Unknown Capacitance can also be found by the Schering's bridge as follows.

$$D_1 = \omega C_1 R_1$$

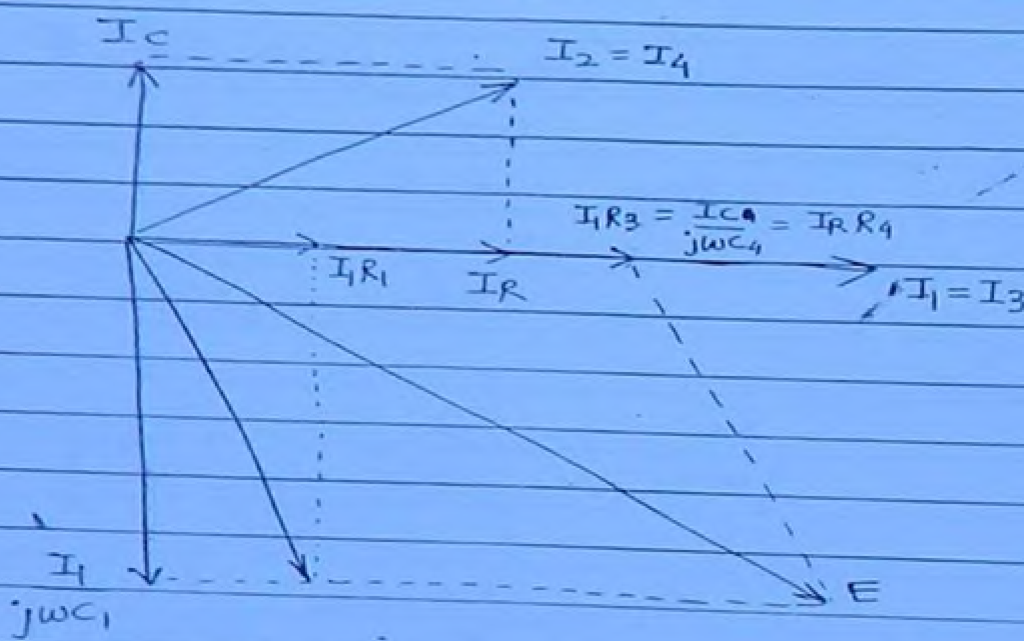
$$= \omega \left(\frac{R_4 \cancel{C_2}}{\cancel{R_3}} \right) \left(\frac{C_4 \cancel{R_3}}{\cancel{C_2}} \right)$$

$$\therefore D_1 = \omega C_4 R_4$$

DATE : / /

Phasor Diagram :

(182)



Procedure :

1. The Current I_1 through the arm AB is taken as the reference and at balance $I_1 = I_3$, as $Id = 0$.

2. The Voltage drop across the resistance R_1 (I_1R_1) will be in phase with I_1. and the Voltage drop across the Capacitor C_1 lags I_1 by $90°$.

3. The phasor sum of I_1R_1 and $\left(\frac{I_1}{j\omega C_1}\right)$ is the voltage drop across the arm AB which at balance will be equal to the

voltage drop across arm AD ($E_1 = E_2$).

183

4. The voltage drop across the arm BC ($I_1 R_3$) will be in phase with I_1 and at balance will be equal to the voltage drop across the arm CD $\left(\frac{I_c}{j\omega C_4} = I_R R_4 = E_4 \right)$ $(E_3 = E_4)$.

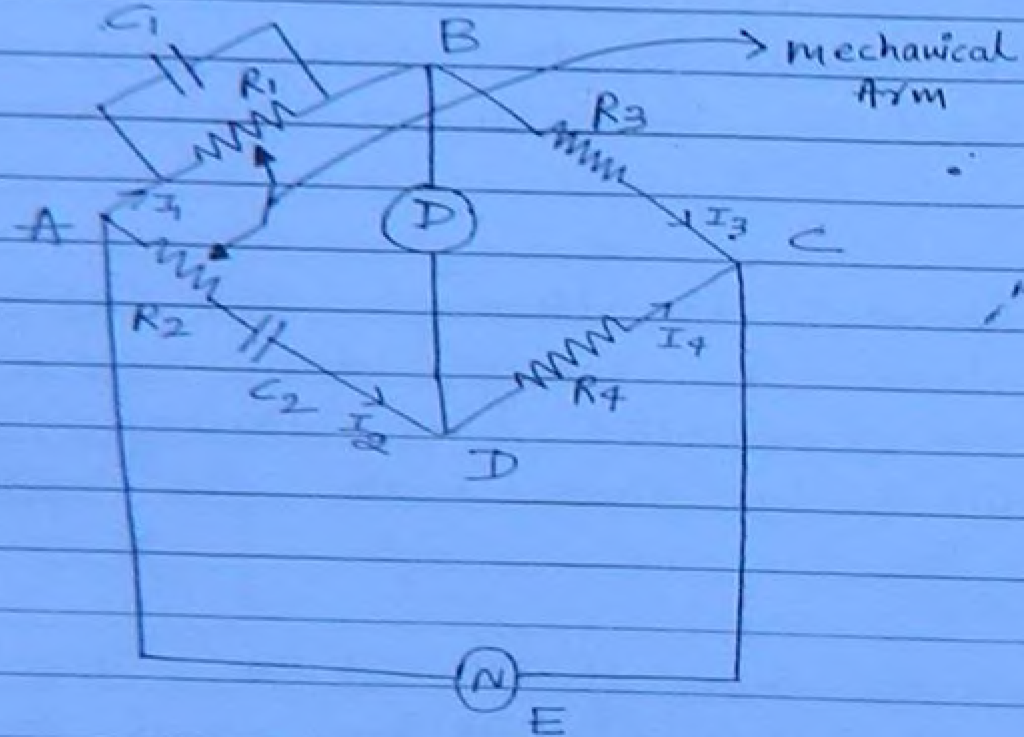
5. The Current I_c through the Capacitor C_4 will lead the Voltage drop across it by 90° and the Current I_R through the resistor R_4 will be in phase with the Voltage drop across R_4.

6. The phasor sum of I_c and I_R is the Current I_2 Which at balance will be equal to the Current through the arm CD (i.e I_4).

7. The phasor sum of $E_1 = E_2$ and $E_3 = E_4$ is the supply voltage E.

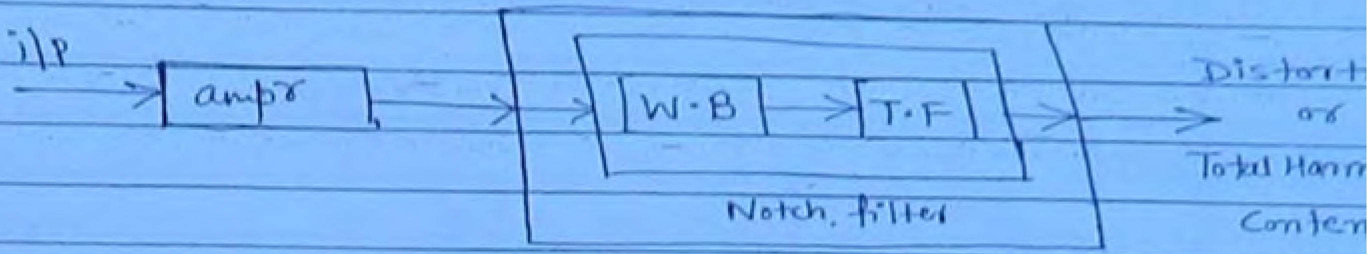
Measurement of frequency Wein's Bridge:

184



The Wein's bridge is a frequency measuring ckt. which also finds applications in

- (i) High freq^n oscillator & amp^r ckt. where it is used as a freq^n selecting device.
- (ii) A Total harmonic distortion Analyzer. Where it is used as a "Notch filter".



At balance, we have, 183

$$Z_1 Z_4 = Z_2 Z_3$$

Where,

$$Z_1 = \frac{R_1}{1 + j\omega C_1 R_1}$$

$$Z_2 = R_2 + \frac{1}{j\omega C_2}$$

$$Z_3 = R_3$$

$$Z_4 = R_4$$

$$\left(\frac{R_1}{1+j\omega C_1 R_1}\right) R_4 = R_3 \left(R_2 + \frac{1}{j\omega C_2}\right)$$

or,
$$\frac{R_1 R_4}{1 + j\omega C_1 R_1} = R_2 R_3 + \frac{R_3}{j\omega C_2}$$

$$\therefore \quad R_1 R_4 = R_2 R_3 + j\omega C_1 R_1 R_2 R_3 + \frac{R_3}{j\omega C_2} + \frac{C_1 R_1 R_3}{C_2}$$

Separating and equating the real and imaginary components we have,

$$R_1 R_4 = R_2 R_3 + \frac{C_1 R_1 R_3}{C_2}$$

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2} \quad \text{--- (1)}$$

186

and,

$$j\omega C_1 R_1 R_2 \cancel{R_3} = j\frac{\cancel{R_3}}{\omega C_2}$$

$$\omega^2 = \frac{1}{C_1 C_2 R_1 R_2} \quad \text{--- (2)}$$

At balance, $C_1 = C_2 = C$

$R_1 = R_2 = R$

$\therefore$ Expression - (1) becomes,

$$\frac{R_4}{R_3} = 2$$

or ** or, $R_4 = 2R_3$

Expression - (2) becomes,

$$\omega^2 = \frac{1}{R^2 C^2}$$

$$\omega = \frac{1}{RC}$$

$$\therefore f = \frac{1}{2\pi RC}$$

DATE : / /

Note :

1 In Order to Compensate for the errors due to earth's Capacitance and inter-arm Capacitances of the bridge a "Wagners earthing device" is used.

187

Q1. A Maxwell's Inductance Comparison Bridge consists of ;

Arm AB with Inductance L_1 and an Internal resistance r_1 in series with the non-inductive resistance R.

Arm BC and CD are each a non-inductive resistance of 100Ω.

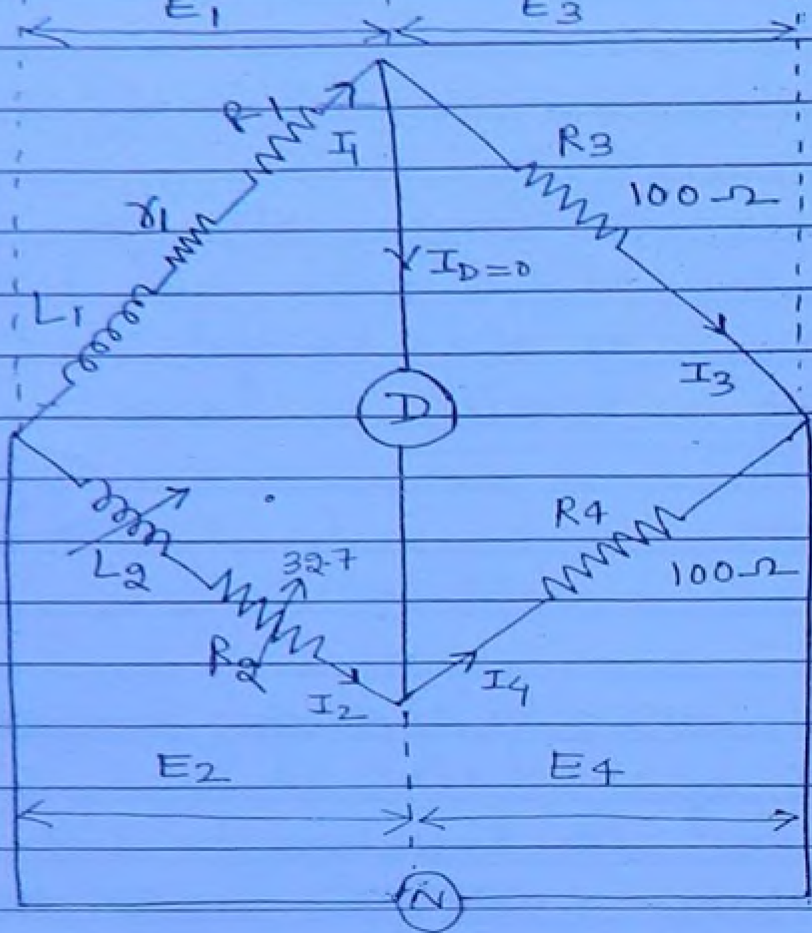
Arm AD is a Standard Variable Inductor L_2 of resistance 32.7Ω.

Balance is obtained when $L_2 = 47.8$ mH and $R = 1.36\Omega$.

Find the resistance and inductance of a coil in arm AB

$\left(L_1 = 47.8 \text{ mH} \quad r_1 = 31.34\,\Omega \right)$

Soln:



188

At Balance,

$$Z_1 Z_4 = Z_2 Z_3$$

where,

$$Z_1 = r_1 + R_1 + j\omega L_1$$

$$Z_2 = \cancel{R_3}\ R_2 + j\omega L_2$$

$$Z_3 = R_3$$

$$Z_4 = R_4$$

$$\therefore (r_1 + R_1 + j\omega L_1) R_4 = (R_2 + j\omega L_2) R_3$$

or, $r_1 R_4 + R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega L_2 R_3$

or. equating real and imaginary parts,

$$\therefore r_1 R_4 + R_1 R_4 = R_2 R_3$$

189

$$\therefore r_1 = \frac{R_2 R_3 - R_1 R_4}{R_4} \quad \text{--- (1)}$$

and $\cancel{j\omega} L_1 R_4 = \cancel{j\omega} L_2 R_3$

$$L_1 = \frac{R_3}{R_4} \cdot L_2 \quad \text{--- (2)}$$

$$\therefore r_1 = \frac{(32.7)(100) - (1.36)(100)}{100}$$

$$\therefore r_1 = 31.34\,\Omega$$

$$L_1 = \cancel{L_2}\frac{(100)}{(100)} \cancel{L_2}(47.8\,mH)$$

$$\therefore L_1 = 47.8\,mH$$

Q2 A Bridge consists of the following

Arm AB : A choke coil having a resistance R_1 and inductance L_1

Arm BC : A non-inductive resistance R_3

Arm CD : A mica Condenser C_4 in series with the non-inductive resistance R_4

Arm DA : A non-inductive resistance R_2.

DATE : / /

When this bridge is feed from a source of 500 Hz. balance is obtained under the following Conditions;

$R_2 = 2410\,\Omega$

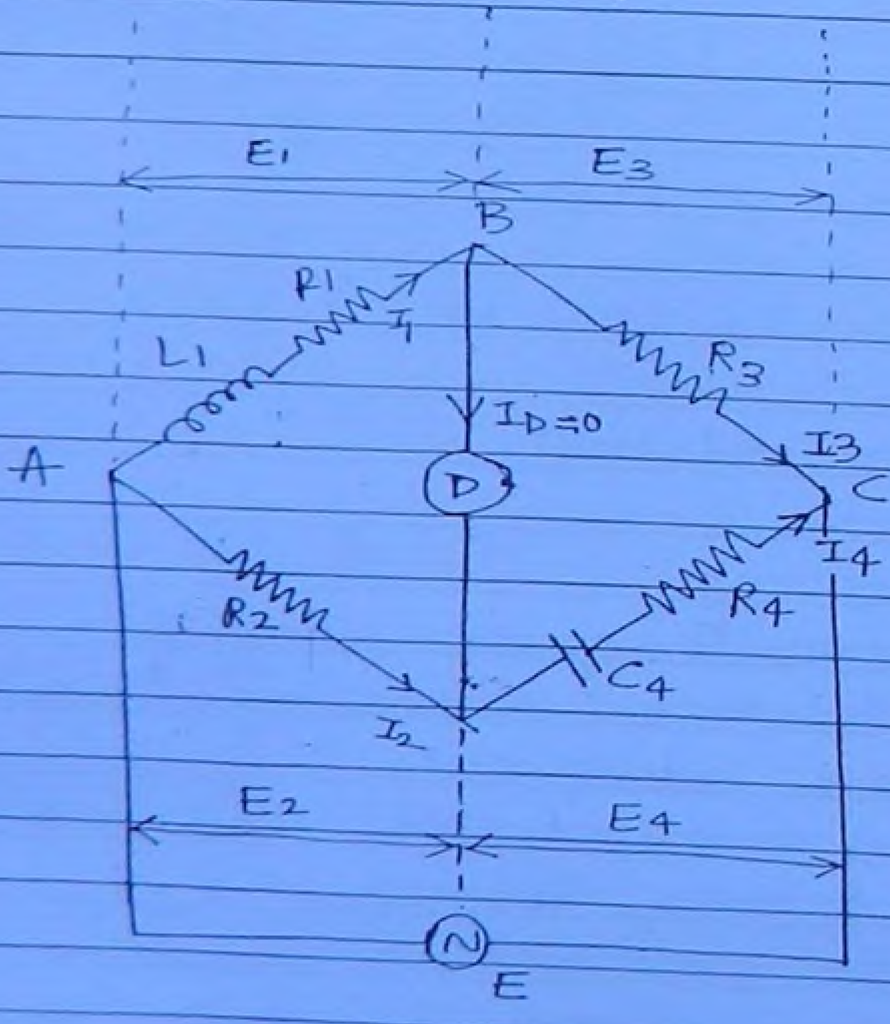
$R_3 = 750\,\Omega$ 190

$C_4 = 0.35\,\mu F$

$R_4 = 64.5\,\Omega$

and the series resistance of the capacitor is $0.4\,\Omega$. Calculate the resistance and inductance of the choke coil.

ln :



At Balance

$$Z_1 Z_4 = Z_2 Z_3$$

Where,

$$Z_1 = R_1 + j\omega L_1$$

191

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_4 = R_4 - \frac{j}{\omega C_4}$$

$$\therefore (R_1 + j\omega L_1)\left(R_4 - \frac{j}{\omega C_4}\right) = R_2 R_3$$

or, $R_1 R_4 - \dfrac{R_1 j}{\omega C_4} + R_4 \cdot j\omega L_1 + \dfrac{L_1}{C_4} = R_2 R_3$

or, $\cancel{j\omega R_1 R_4 C_4 + R_1 + R_4 C_4 L_1 j^2 \omega^2 + \frac{L_1}{C_4} = R_2 R_3}$

or, $\cancel{j\omega R_1 R_4 C_4 - \omega^2 R_4 C_4 L_1 + R_1 + \frac{L_1}{C_4} = R_2 R_3}$

Equating real and imaginary parts we get,

$$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3$$

$$\therefore L_1 = (R_2 R_3 - R_1 R_4) C_4 \quad \text{—— (1)}$$

and $\cancel{j}\omega L_1 R_4 = \dfrac{R_1 \cancel{j}}{\omega C_4}$

$$R_1 = \omega^2 L_1 R_4 C_4 \quad \text{—— (2)}$$

Put value of L_1 in R_1 (192)
we get,

$$R_1 = \omega^2 L_1 R_4 C_4$$
$$= \omega^2 (R_2 R_3 C_4 - R_1 R_4 C_4) R_4 C_4$$

$$R_1 = \omega^2 R_2 R_3 R_4 C_4^2 - \omega^2 R_1 R_4^2 C_4^2$$

Put this value of R_1 in eq of L_1,
we get,

$$L_1 = (R_2 R_3 - R_1 R_4) C_4$$
$$= R_2 R_3 C_4 - R_1 R_4 C_4$$
$$= R_2 R_3 C_4 - \omega^2 (R_2 R_3 R_4 C_4^2 - \cancel{\omega^2} R_1 R_4 C_4) R_4 C_4 . C_4$$
$$\therefore L_1 = R_2 R_3 C_4 - \omega^2 R_2 R_3 R_4^2 C_4^4 - \omega^2 R_1 R_4^2 C_4^3$$

$$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3 \quad \text{——— (1)}$$

$$\cancel{j} \omega L_1 R_4 = \cancel{j} \frac{R_1}{\omega C_4}$$
$$L_1 = \frac{R_1}{\omega^2 R_4 C_4} \quad \text{——— (2)}$$

Put this value of L_1 in eq -(1)
we get,

$$R_1 R_4 + \frac{R_1}{\omega^2 R_4 C_4^2} = R_2 R_3$$

or, $R_1\left(R_4 + \frac{1}{\omega^2 R_4 C_4^2}\right) = R_2R_3$

193

or, $R_1\left(\frac{1+\omega^2 R_4^2 C_4^2}{\omega^2 R_4 C_4^2}\right) = R_2R_3$

$$\therefore \quad R_1 = \frac{(R_2R_3)\omega^2 R_4 C_4^2}{(1+\omega^2 R_4^2 C_4^2)}$$

$$\therefore \quad R_1 = \frac{\omega^2 R_2 R_3 R_4 C_4^2}{(1+\omega^2 R_4^2 C_4^2)} \qquad \text{— (3)}$$

Now, Put this R_1 in eq – (2).

$$\therefore \quad L_1 = \frac{\cancel{\omega^2} R_2 R_3 \cancel{R_4} C_4^{\cancel{2}}}{\cancel{\omega^2} \cancel{R_4} \cancel{C_4}(1+\omega^2 R_4^2 C_4^2)}$$

$$\therefore \quad L_1 = \frac{R_2 R_3 C_4}{(1+\omega^2 R_4^2 C_4^2)}$$

Putting the given values :

$$R_1 = \frac{(2\pi \times 500)^2 \cdot (2410)(750)(67.5 + 0.4)(0.35 \times 10^{-6})^2}{(1+(2\pi \times 500)^2 (64.5+0.4)^2 (0.35 \times 10^{-6})^2}$$

$$= \frac{423951201.1}{1.005092}$$

$$=$$

$$L_1 = \frac{(2410)(750)(64.5) \times 10^{-6}}{(1+(2\pi \times 500)^2 (64.5+0.4)^2 (0.35 \times 10^{-6})^2}$$

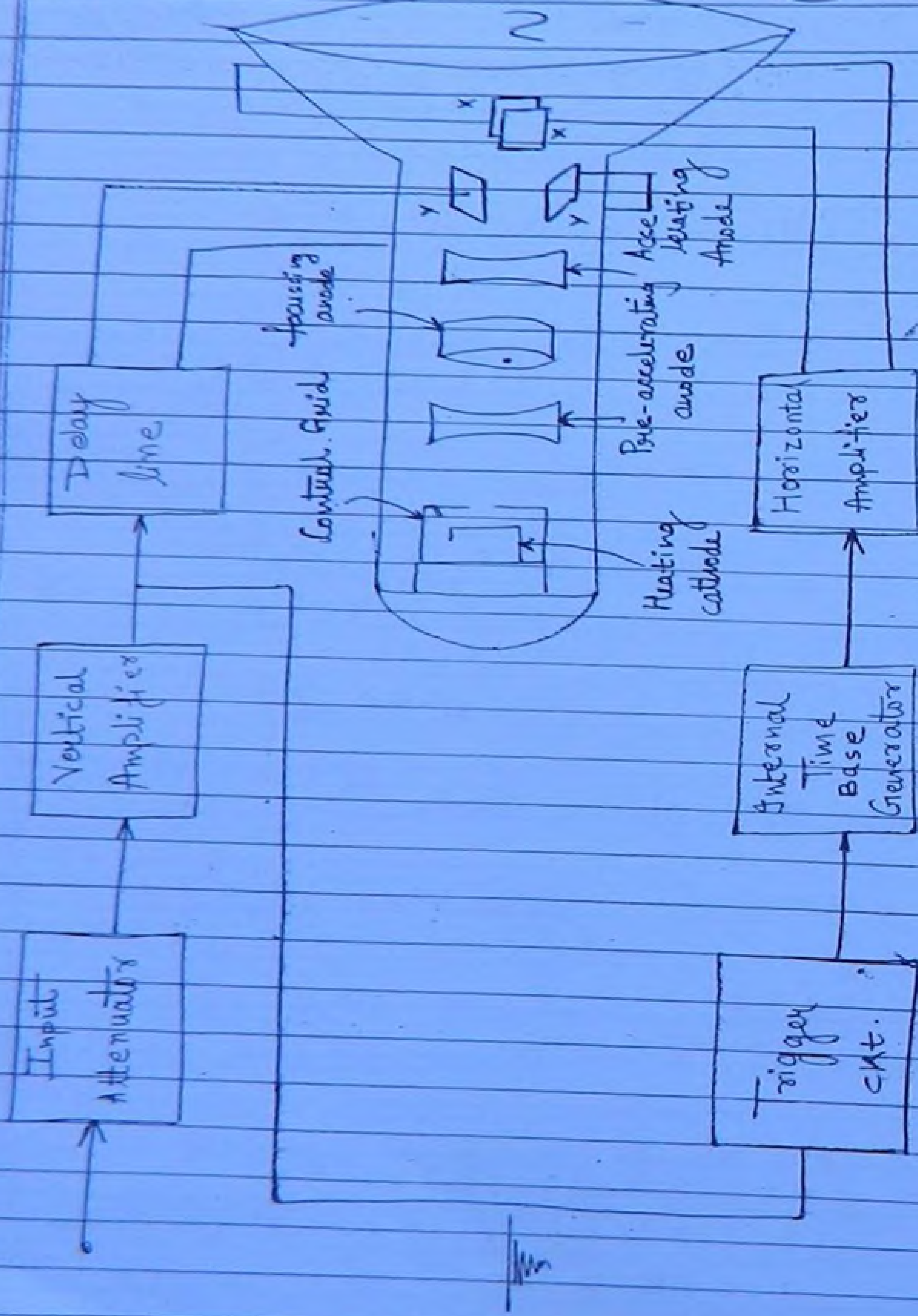
$$= \frac{116.58}{1.005}$$

$$= 115.98$$

Cathode Ray Oscilloscope :

Block diagram of CRO :

194



-1. The above Schematic shows a simplified block diagram of a Cathode ray Oscilloscope

-2. The i/p to the CRO is given to the input attenuator across the ground.

(195)

-3. The utility of the i/p attenuator is to attenuate high value signals in order to protect the internal circuitary of CRO

-4. The i/p attenuator basically consist of resistor ladder n/w's and it works as a protection mechanism for the protectio circuitary of CRO.

-5. The o/p of the attenuator is given to the vertical amplifier. Which basically consists of cascaded sections of Unity gain and Push-pull amplifiers.

-6. The objective of the vertical amplifier is to amplify the i/p signal ~~so~~ to the levels that can create the Considerable potential difference across the Y-Y plates of the cathode ray tube.

Note: The potential difference across the Y-Y or the vertical deflection plates is a function of the magnitude of the i/p.

7. A part of the o/p of the vertical amplifier is given to the horizontal deflection system.

(196)

8. The trigger ckt generates a trigger pulse that initiates the operation of the internal time-base generator

9. The internal time base generator is a UJT based sweep signal generator whose utility is to generate a voltage signal, that is a function of the constant time period.

10. The o/p of the internal time base generator is amplified by the horizontal ampr which is similar in construction to the vertical amplifier.

11. The utility of the horizontal ampr is to amplify its i/p to the levels considered sufficient to produce a considerable potential difference across the X-X plates.

Note: The potential difference across the X-X or the horizontal plates of CRT is proportional to the o/p of the internal time base generator which is a function of

a constant time period.

12. Imp The utility of the delay line in the vertical deflection system is to synchronize the o/p's of the X-X and Y-Y plates to appear across their respective plates at same instance.

13. Imp In absence of the delay line ckt, the potential difference across Y-Y plates would have appeared earlier than potential difference across X-X plates as the horizontal deflection of the CRO which is triggered by the vertical deflection system would require some time to give its o/p.

Imp

14. In the absence of the delay line ckt in CRO the leading edge of the signal is lost.

15. The Cathode ray tube is basically a Vacuum evaporated glass tube maintained at a pressure of 1 torr (very small pressure).

It Basically consists of a heated cathode which functions as a electron emitter.

The Surface of the heated cathode is coated with Sprontiom which is basically used to catalyse the emission of electrons.

16. The electrons emitted by the heated cathode

are focussed into a thin beam by a Control grid which is placed at a few hundered volt more +ve than a heated cathode.

198

Note:
* 17. The potential across the Control grid is
ASQ controlled by the intensity Control on the front panel of a CRO.

18. This beam of electrons is further accelerated by the set of 3 electrodes namely, (i) The pre-accelerating Anode.
(ii) The focussing Anode.
(iii) The Accelerating Anode.

Note:

19. These 3 set of anodes are placed a few thousands volts higher than the Control grid.

- The Pre-accelerating Anode and the accelerating anode are placed at equipotential, while the focussing anode is placed slightly below the potential of these two anodes.

Imp * • The potential across the set of these 3 Anodes is Controlled by the focussing control on the front panel of CRO.

20. All the components from the heated cathode to the accelerating anode put together are known as the electron-gun assembly of the CRT. Whose utility is to produce the beam of electron that are moving at a high velocity towards the screen.

199

21. This beam of electrons is deflected in the vertical plane by the patential difference across the vertical deflection plates. The deflection beam proportional to the patential difference which in turn is proportional to the magnitude of the i/p.

22. This deflected beam of electrons passes through the horizontal deflection plates which spread them in the horizontal plane.

This spreading beam proportional to the patential difference across the horizontal deflection plales which in turn is a function of a constant time period.

23 This beam of electron goes and hits the internal surface of the screen of cathode ray tube which is coated with the material that exhibits the property of floreses.

24. Thus, the pattern that depicts the pattern

variation of the magnitude w.r.t the time period is formed on the screen of the CRT.

(200)

25. As the beam of electrons hits the internal surface of the CRT, a cloud of electrons are formed near the screen which could be a potential source of noise in the o/p

26. These clouds of electrons are absorbed by a material called acquadac (which is an aqueous solution of graphite that is coated on the internal ~~sur~~ walls of the CRT).

Note:

Imp 1. The cathode ray tube utilizes the electrostatic focussing mechanism in order to produce the image. Whereas, a TV screen utilizes the electromagnetic focussing mechanism.

2. Electromagnetic focussing mechanism is used in instances where the area of the sweep is large and the sensitivity requirements are high.

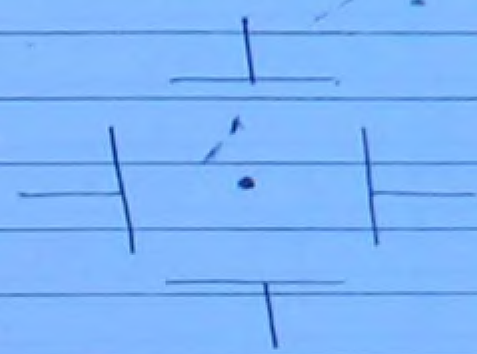
Whereas, electrostatic focussing mechanism is used in instances where the area of sweep is small, the image is

formed at the Centre of the Screen and the accuracy requirements are high.

201

Pattern formation in the CRO:

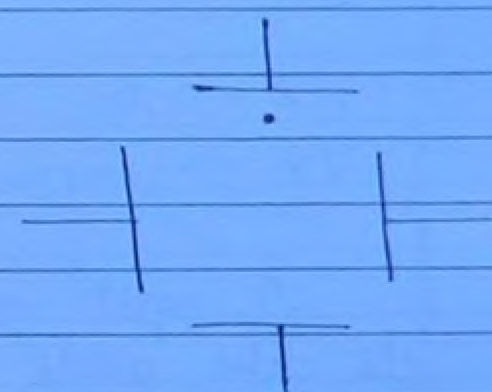
Case 1:



XX → } Grounded
YY → }

Spot is formed at the Centre.

Case 2:



XX → Grounded
YY. → D.C

- A spot is formed in the Vertical nearer to that plate which is more +ve.

Case 3:

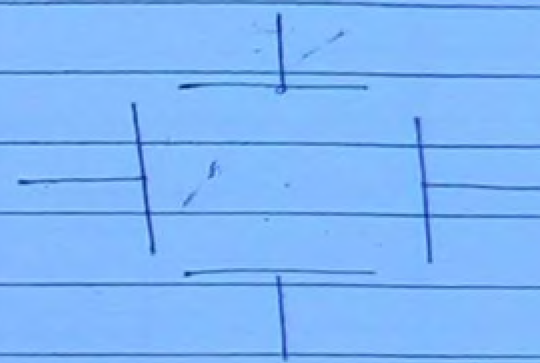
XX → Grounded
YY → AC

A Vertical straight line

case 8 :

X X ⟶ AC
Y Y ⟶ DC

A horizontal line nearer to the Y plate that is more +ve.

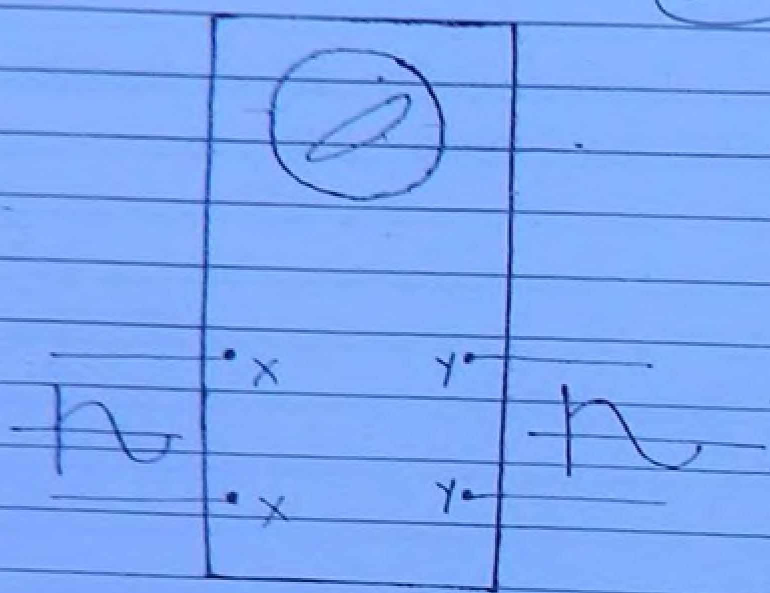


case 9 :

X X ⟶ Time base
Y Y ⟶

Measurement of Phase using Lissagious Pattern.

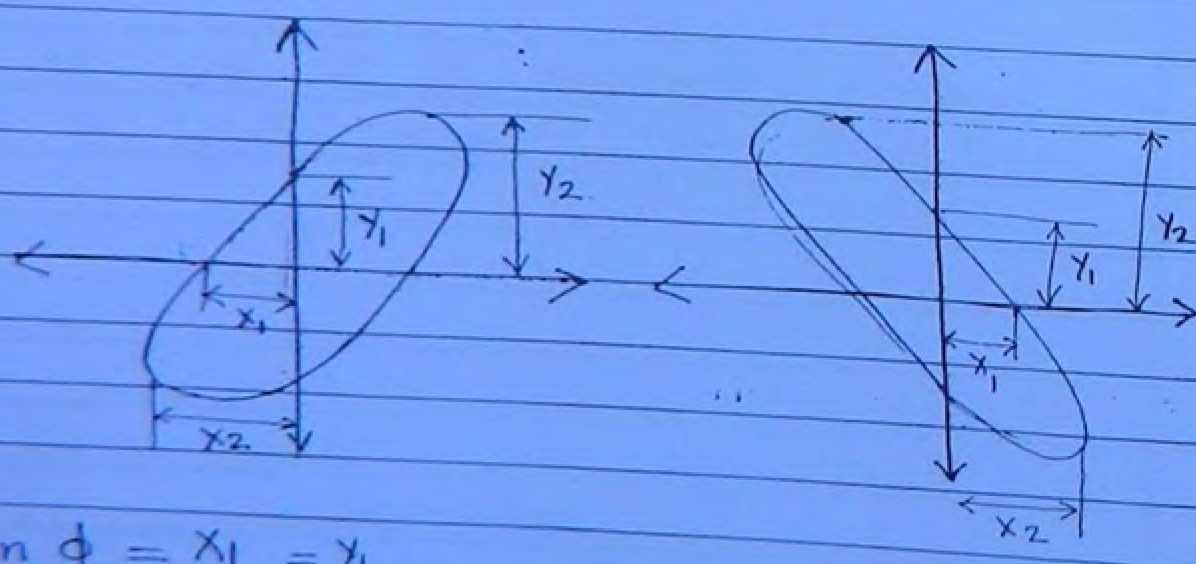
204



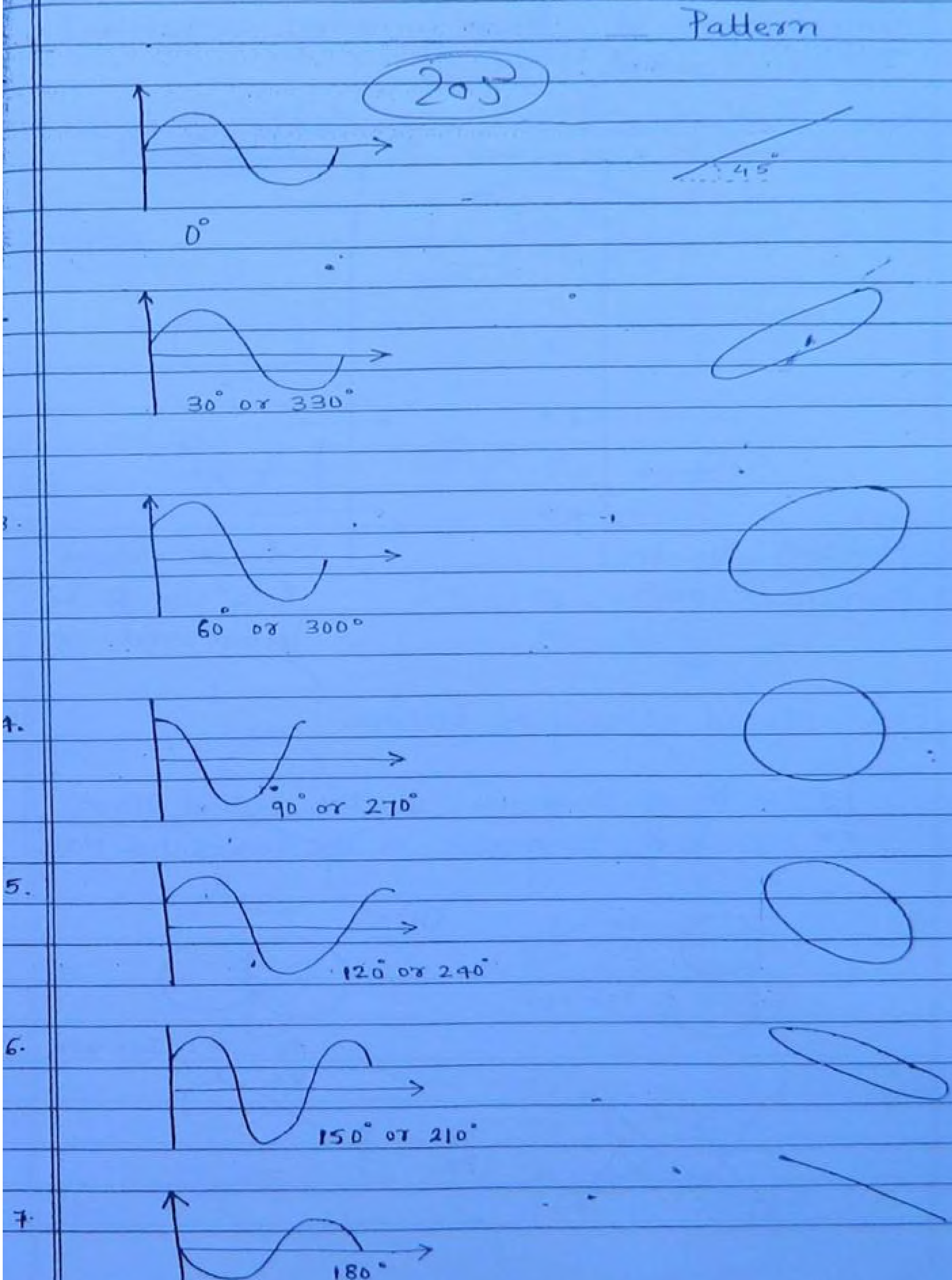
Pre Condition :

frequency of both the signals should be same.

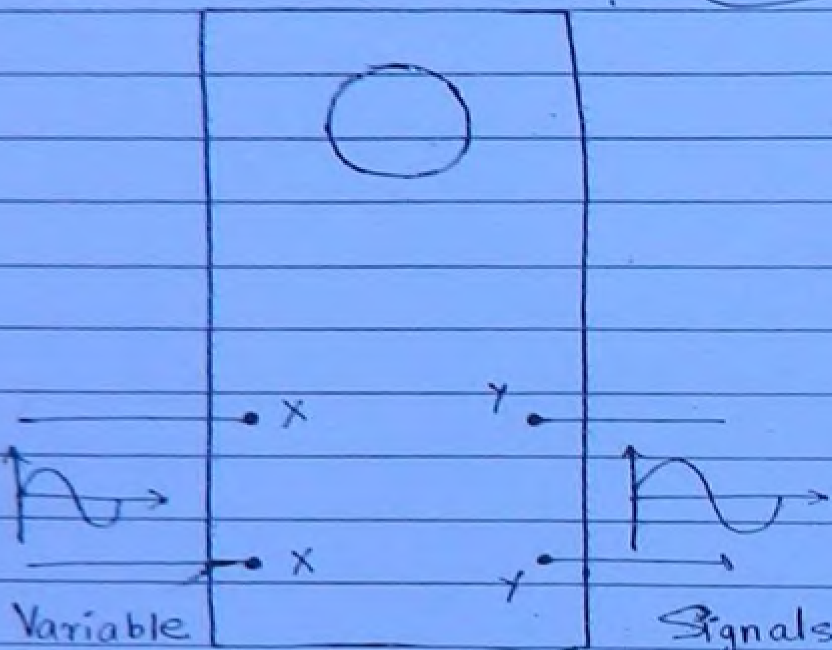
Example :



$$\sin \phi = \frac{X_1}{X_2} = \frac{Y_1}{Y_2}$$


Pattern
205
45°
0°
30° or 330°
3.
60° or 300°
4.
90° or 270°
5.
120° or 240°
6.
150° or 210°
7.
180°

Measurement of frequency using Lissagious Pattern method:



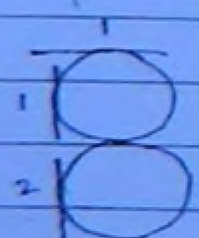
Standard Variable Source of freq^n

Signals whose freq^n is to be measured.

1. For closed Lissajous pattern

$$\frac{F_y}{F_x} = \frac{\text{No. of tangencies in the vertical Plane}}{\text{No. of tangencies in the horizontal Plane}}$$

(i)



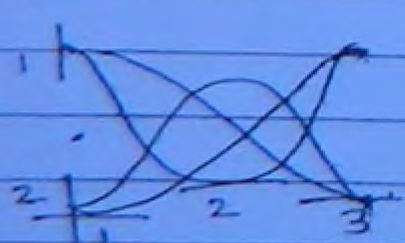
$\frac{F_y}{F_x} = \frac{1}{2}$

$F_y = \frac{F_x}{2}$

(ii)

$\frac{F_y}{F_x} = \frac{2}{1}$; $F_y = 2F_x$

(iii)



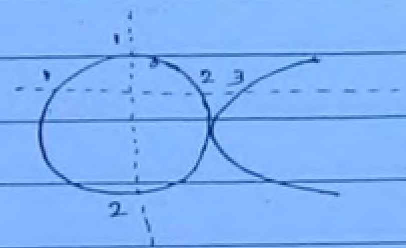
$\frac{F_y}{F_x} = \frac{3}{2}$

2. For open ended Lissajous pattern:

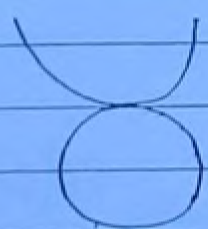
$$\frac{F_y}{F_x} = \frac{\text{Max no. of intersection in Horizontal Plane}}{\text{Max no. of Intersection in Vertical Plane}}$$

207

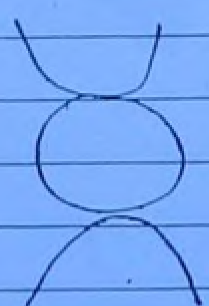
Examples:

1. 

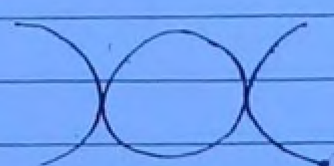
$\frac{F_y}{F_x} = \frac{2}{3}$

2. 

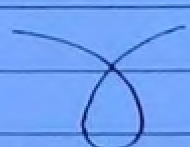
$\frac{F_y}{F_x} = \frac{2}{3}$

3. 

$\frac{F_y}{F_x} = \frac{2}{4}$

4. 

$\frac{F_y}{F_x} = \frac{4}{2}$

5. 

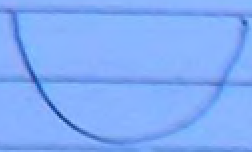
$\frac{F_y}{F_x} = \frac{2}{3}$

6. 

$\frac{F_y}{F_x} = \frac{3}{2}$

7. 

$\frac{F_y}{F_x} = \frac{1}{2}$

8. 

$$\frac{F_y}{F_x} = \frac{2}{1}$$

208

Govt OVS

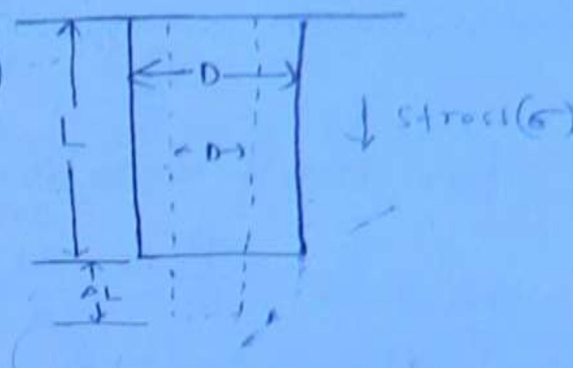
Measurment of strain: Vimp

(Neumericals are asked)

genrally strain gauze is used

Principle: Body stressed → it changes its resistance and change in resistance ∝ applied stress.

$$\boxed{\text{Strain (microstrain)} = \frac{\Delta L}{L}} \quad 200$$



To prove

$$\boxed{\frac{\Delta R}{R} = K\frac{\Delta L}{L}}$$

Classification of strain is based on the value of K.

Where K is a constant known as gauze factor.

We know that

Resistance R can be expressed as

$$R = \rho\frac{L}{A}$$

applying Log on both sides

$$\log R = \log L - \log A + \log \rho \quad -(1)$$

differentiating above expression w.r.t σ

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{L}\frac{dL}{d\sigma} - \frac{1}{A}\frac{dA}{d\sigma} + \frac{1}{\rho}\frac{d\rho}{d\sigma} \quad -(2)$$

Here A the area is taken as

$$A = \frac{\pi D^2}{4}$$

$$\frac{dA}{d\sigma} = \frac{\pi D}{2}\frac{dD}{d\sigma}$$

$$\frac{1}{A}\frac{dA}{d\sigma} = \frac{4}{\pi D^2} \times \frac{\pi D}{2}\frac{dD}{d\sigma} = \frac{2}{D}\frac{dD}{d\sigma} \quad (3)$$

substituting the value of $\frac{1}{A}\frac{dA}{d\sigma}$ in exp(2), we have

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{L}\frac{dL}{d\sigma} - \frac{2}{D}\frac{dD}{d\sigma} + \frac{1}{\rho}\frac{d\rho}{d\sigma} \quad -(4)$$

from the poisson ratio, we have

210

$$v = \frac{-\Delta D/D}{\Delta L/L} \quad (-\because \text{dia is dec})$$

$$-\frac{\Delta D}{D} = v\frac{\Delta L}{L} \quad -(5)$$

for small variations, the exp(4) can be written as

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - 2\frac{\Delta D}{D} + \frac{\Delta \rho}{\rho}$$

from expression (5), we have

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2v\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$

$$\boxed{\frac{\Delta R}{R} = \frac{\Delta L}{L}\left(1 + 2v + \frac{\Delta\rho/\rho}{\Delta L/L}\right)}$$

$$k = 1 + 2v + \frac{\Delta\rho/\rho}{\Delta L/L}$$

The term $\left(1 + 2v + \frac{\Delta\rho/\rho}{\Delta L/L}\right)$ is known as the genralised expression for gauze factor of a strain gauze

- If the change in resistance of a strain gauze is due to its change in the mechanical dimension then the term $\Delta\rho/\rho/\Delta L/L$ becomes 0

These types of strain gauze's are metal wire strain gauze's whose gauze factor lies b/w. (-5 to +5)

Hence the expression for the gauze factor is given as $\boxed{g_m = 1+2\nu}$ (211)

→ The strain gauze which change their resistances due to change in resistivity are basically semi-conductor strain gauze's which base their operation on the peizo resistive effect

The typical values of gauze factor of s.c strain gauzes ranges from 500 to 3000.

Q A strain gauze with a nominal resistance of 120 Ω and gauze factor of 2 undergoes a strain of 10^{-5}. What is the change in resistance in response to a strain

IES 04

$$g.f = g_m = 2 = 1+2V.$$

$$\frac{\Delta L}{L} = 10^{-5}$$

$$\frac{\Delta R}{R} = \frac{\Delta L}{L}(1+2\nu)$$

$$\Delta R = 120 \times 2 \times 10^{-5}$$

$$= 2.4 \times 10^{-3}\ \Omega$$

$$= 2.4\ m\Omega$$

IES 1997

Q A strain gauze bridge measures, the strain in the cantilever, where the gauze is fixed. With the strain "ε", the gauze resistance inc from 110 Ω to 110.52 Ω If the gauze factor is 2.30, the strain in the cantilever will be

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} \times g.f$$

$$\Rightarrow \frac{0.52}{110} \times \frac{1}{2.3} = \frac{\Delta L}{L} = 2.055 \times 10^{-3}$$

Q A resistance strain gauze is fastened to a beam subjected to a strain of 1×10^{-6}, yeilding a resistance change of 240 μΩ. If the original resistance of strain gauze is 120Ω, the gauze factor would be

212

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} \times g f$$

$$\frac{240 \times 10^{-6}}{120} = 10^{-6} \times g f \Rightarrow g \cdot f = 2$$

IAS

Q A resistance strain gauze, with a gouze factor of 2 is fastened to steel member, subjected to a stress of 10.5×10^{4} kN/m², the modulus of elasticity of steel is 2.1×10^{8} kN/m², the change of resistance due to the stress in strain gauze is

(a) 0.1% (b) 0.2% (c) 1% (d) 10%

$$\Delta R = 10.5 \times 2$$

$$Y = \frac{\text{stress}}{\text{strain}}$$

$$\Rightarrow \text{strain} = \frac{10.5 \times 10^{4}}{2.1 \times 10^{8}}$$

$$= \cancel{10^{-4}}\ 0.5$$

$$\frac{\Delta R}{R} \times 100 = \cancel{10^{-4}} \times 2 \times 0.5 \times \cancel{100} \times 10^{-3}$$

$$= \cancel{\tfrac{1}{8}}\ \cancel{0.1} \times 10^{-3} \times 100$$

$$= 0.1\%$$

(very large) (Range)

– ve temp coefficient = Thermistor (150-200°C

→ Highly sensitive

Up to 50° → Thermistor expression fails

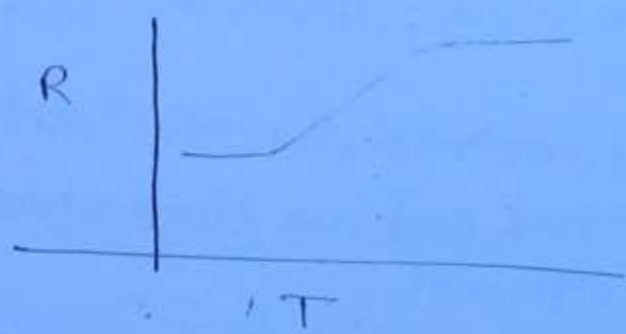
↳ so RTD is used

The most commonly used method for the measurmes of temperature are
(i) Resistance temp detector (RTD) (213)
(ii) Thermistors (Thermal resistors
(iii) Thermo-couples (An active transducers)

→ RTD based their operation on the fact that pure metals change their resistance at a constant rate w.r.t temperature

Imp These detectors are characterised by a positive temp. coefficient, High linearity, Low sensitivity and High cost

A Typical I/O relationship of RTD, would look like



The expression that relates, the resistance and temperature characteristics of a RTD is given by—

$$\boxed{R_T = R_0(1 + \alpha \Delta T)}$$

Where

$\Delta T = T - T_0$
T_0 - Reference temperature
R_0 - Resistance at Ref temperature
T = Temp. under measurment
R_t = Resistance @ temp T

Q A platinum thermometer has resistance of 100Ω a 25°C ⓐ find its resistance at 65°C, if platinum has $\alpha = 0.00392/°C$ (ii) Thermometer has resistance of 150Ω, calculate the temp?

214

ⓐ $R_1 = R_0(1 + \alpha \Delta T)$

$= 100(1 + 0.00392 \times 40)$

$= 100 \quad (1.1568)$

$= 115.68\ \Omega$

ⓑ

$150 = 100(1 + 0.00392(\theta - 25))$

$50 = (1 + 0.00392\theta - 0.09800)$

$\frac{50 - 0.002}{0.00392} = \theta \qquad \theta = 155$

Thermistor!

Thermistor are thermal resistors are made up of semiconducting material and are characterised by a negative temp. coefficient.

The imp. characteristics of a thermistor are High Non linearity, a limited range (-100 to 300°C) High sensitivity and High Accuracy (±0.01°C)

Thermocouple :—

Bimetallic Junction

due to temp potential → voltage are induced

Thermocouples are active transducers, which base their operation on the see beck effect

These temp. transducers can be further classified as

(i) Base metal thermocouples

(ii) Rare metal Thermocouple

218

Imp (i) Base metal Thermocouple:

(a) Copper — Constanton (− 250°C to 400°C)

(b) Iron — Constanton (− 200°C to 850°C)

(c) Chromel - Alumel (− 200°C to 1100°C)

(d) chromel - constonton (− 200°C to 850°C)

Imp (ii) Rare metal thermocouples:-

(a) Platinum - Rhodium - platinum (0 to 1400°C)

(b) Tungston, Rhenium - Tungston (0 to 2600°C)

(c) Rhodium, Iridium - Iridium (0 to 2100°C)

Accuracy is too high that it can't be expressed in terms of others

(→Reading is given in Absolute terms)
↳ Accuracy is displayed directly.

2K

Digital voltmeter :- (DVM)

various characteristics of digital voltmeter are

(i) Negligible operational power consumption

(ii) High input impedence (MΩ)

(iii) High resolution (1μV on 1 V range)

[Smallest change in i/p that can be detected in o/p] (1mV on 1000V range)

(iv) High Accuracy (± 0.01% of reading)

The display of a digital voltmeter is indicated in terms of $N\frac{1}{2}$ digit display

N digits of digital display are those which can indicate values ranging from (0-9) and the half digit of the digital display is designed to indicate either 0 or 1

The half digit of the digital display indicates the instrument ability to be over range, while the N digits indicates its resolution

The resolution of display of DVM = $1/10^N$

$R_{display} = 1/10^N$ (N → no. of full digits)

$$\text{Resolution of meter for a given Range } (R_{\text{Resolution meter}}) = \frac{1}{10^N} \times \text{max Range}$$

imp

Resolution of display = Resolution of 1v range

Q A DVM is designed with $4\frac{1}{2}$ digit display find the resolution of meter for (0-1V) range and (0-100V) range

$$R_{meter}^{(1V)} = \frac{1}{10^N} \times \text{max. Range}$$

$$= \frac{1}{10^4} \times 1V$$

$$= 10^{-4}$$

$$R_{meter}^{(100V)} = 10^{-4} \times 100$$

$$= 10^{-2} = 0.01$$

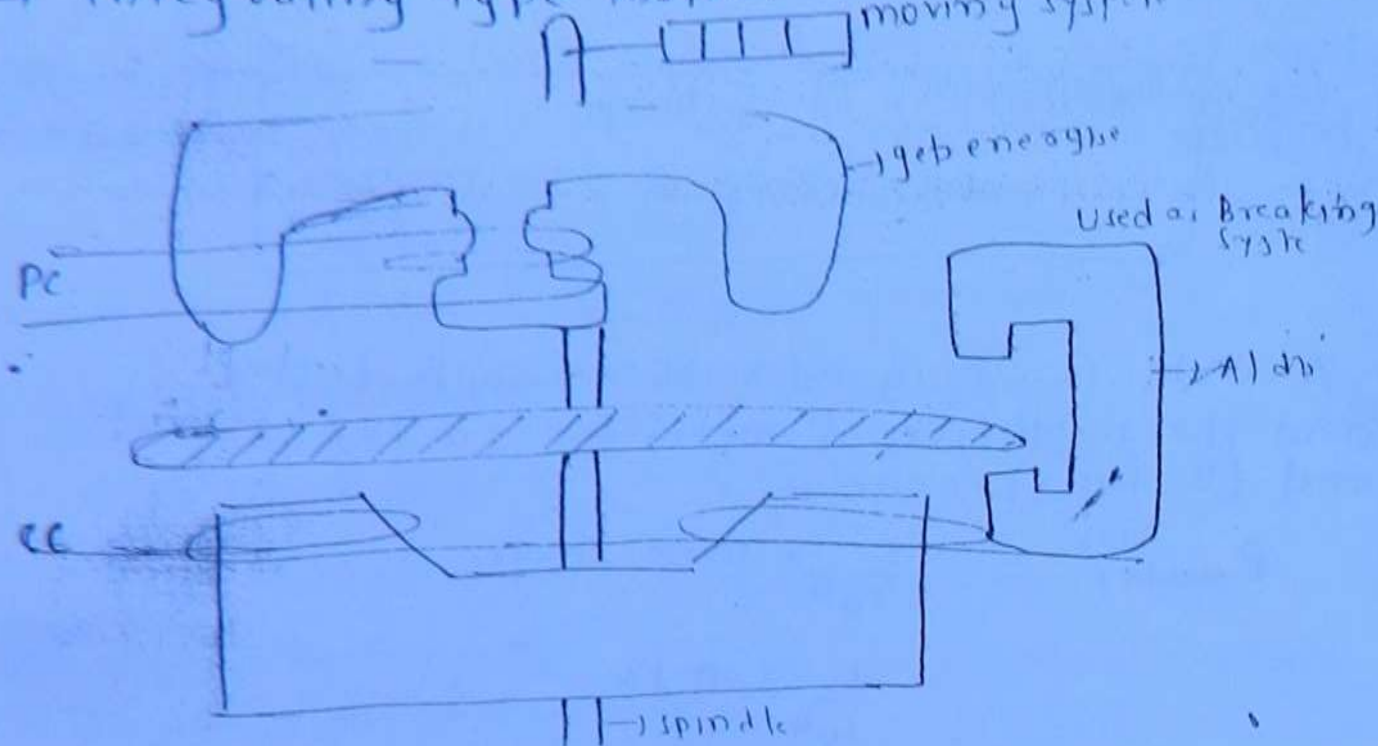
Q How would 0.3749 be displayed in DVM having its display as a $4\frac{1}{2}$ digit display, working on the ranges of 0-1v, 0-10v, 0-100v.

0-1	0 .	3	7	4	9
0-10	0	0 .	3	7	4
0-100	0	0	0 .	3	7

Energy meter

218

- modified induction type instru
- integrating type instru.



Shunt mag → carry ~~with~~ load current
↳ connected with supply volt

Al disc is mounted in moving spindle

Breaking system → perm. mag at one corner

Reg. system $\xrightarrow{\text{resemble}}$ (meter on Bite)

Driving → drives moving system
↑
controls by breaking → Read by Reg system

$I_{pc} \propto$ supply volt → ϕ_{pc} → $(pc \to) I_{e\,pc}$

$I_{cc} \propto$ load current → ϕ_{cc} → I_{cc} → $I_{e\,cc}$

2 flux induced in Air gap